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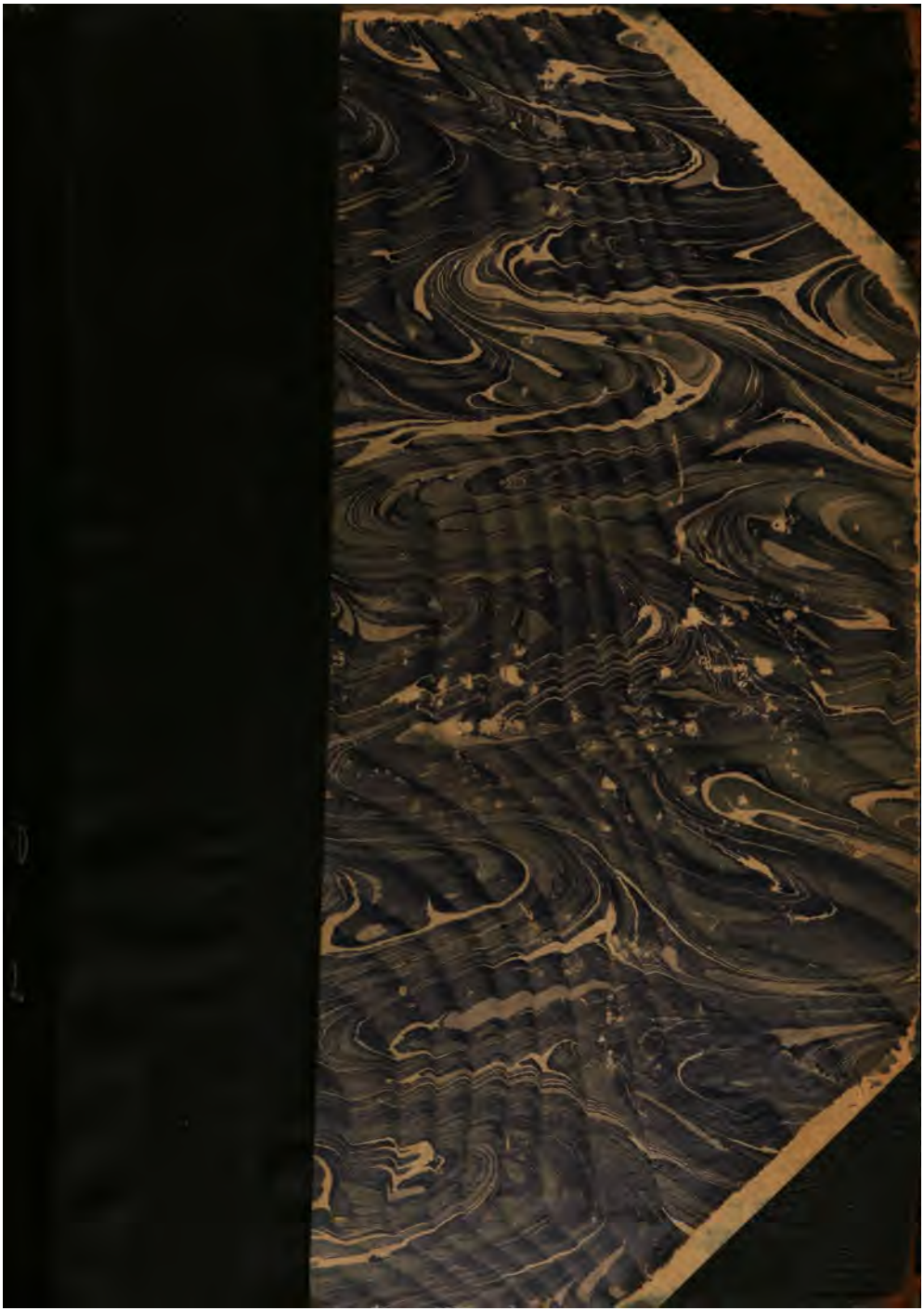

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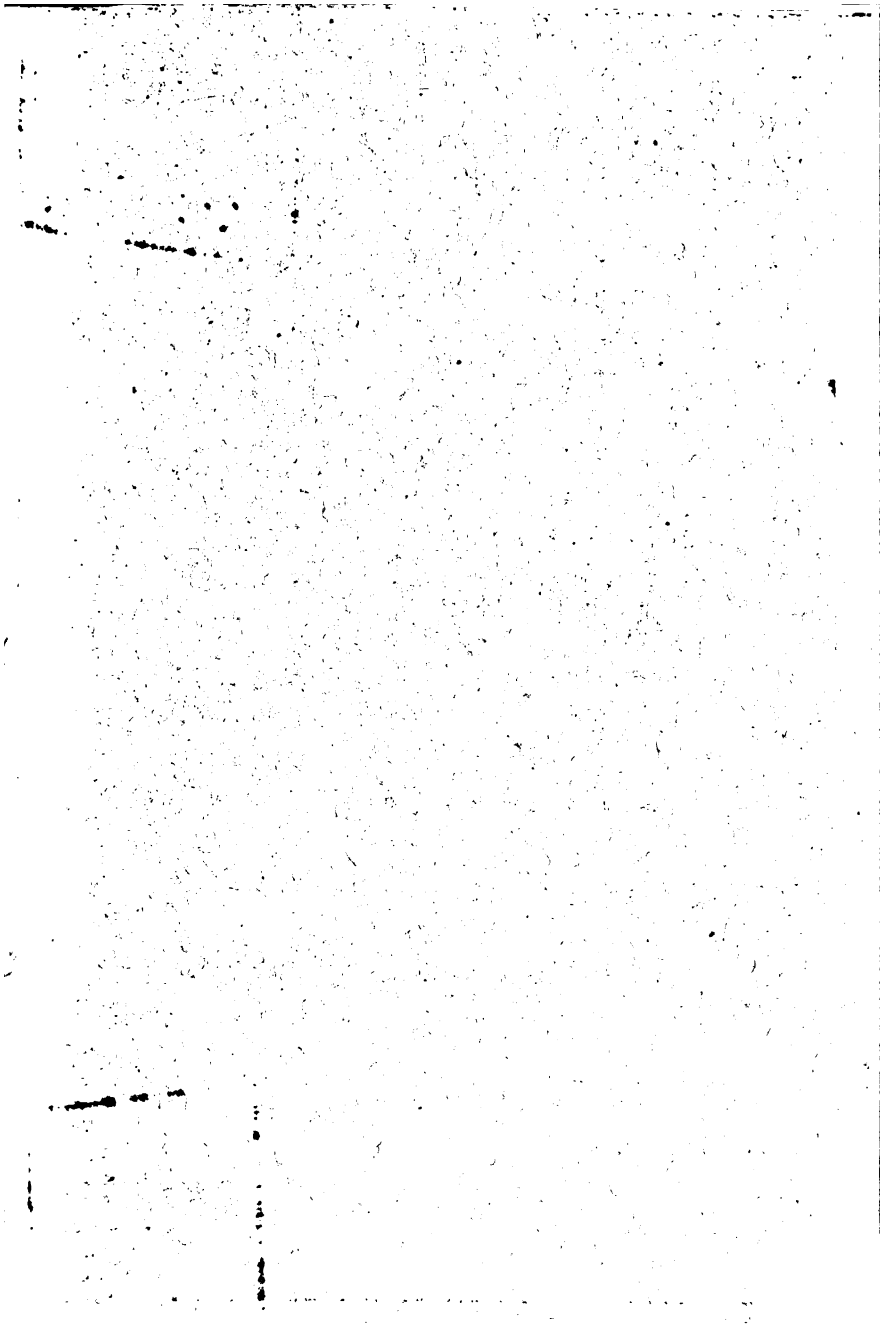

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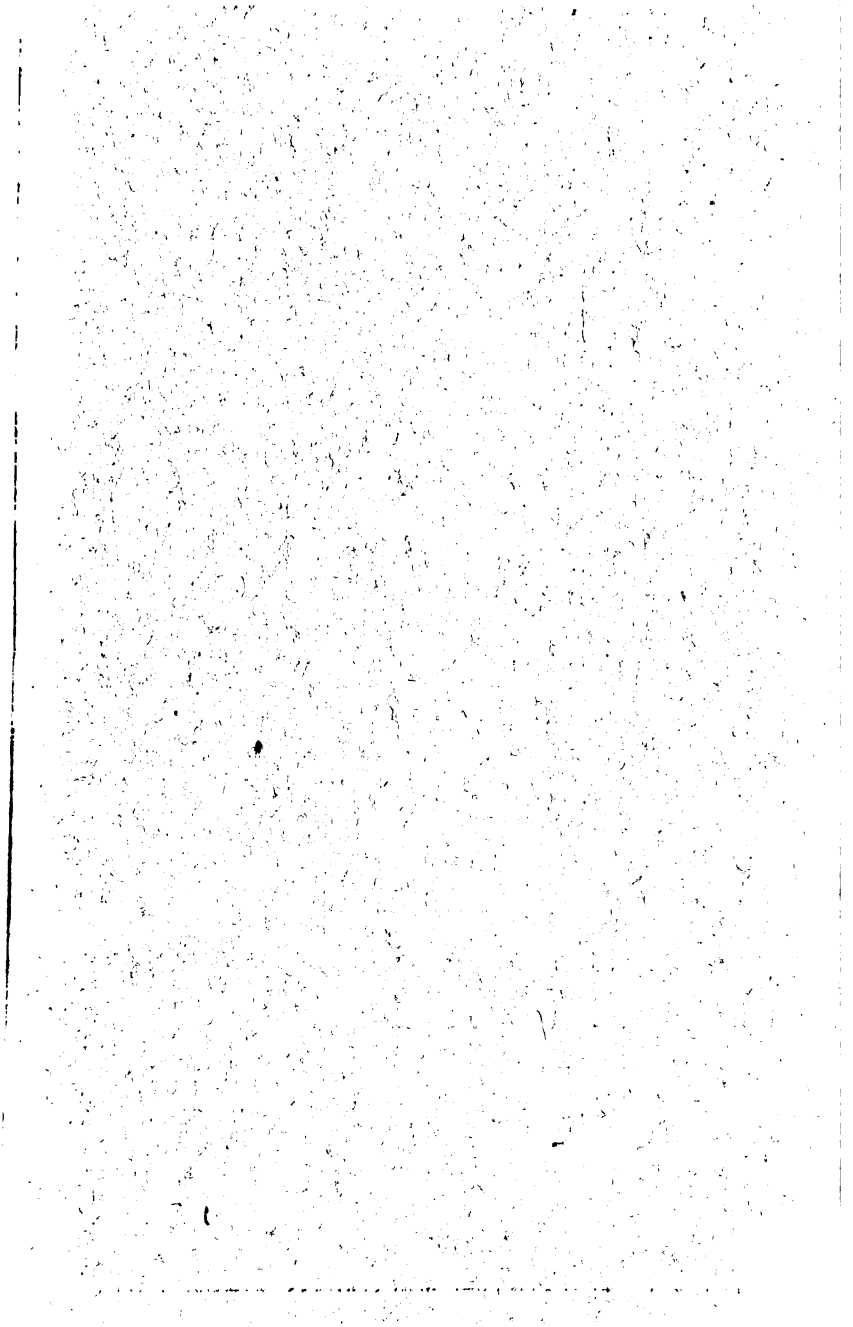

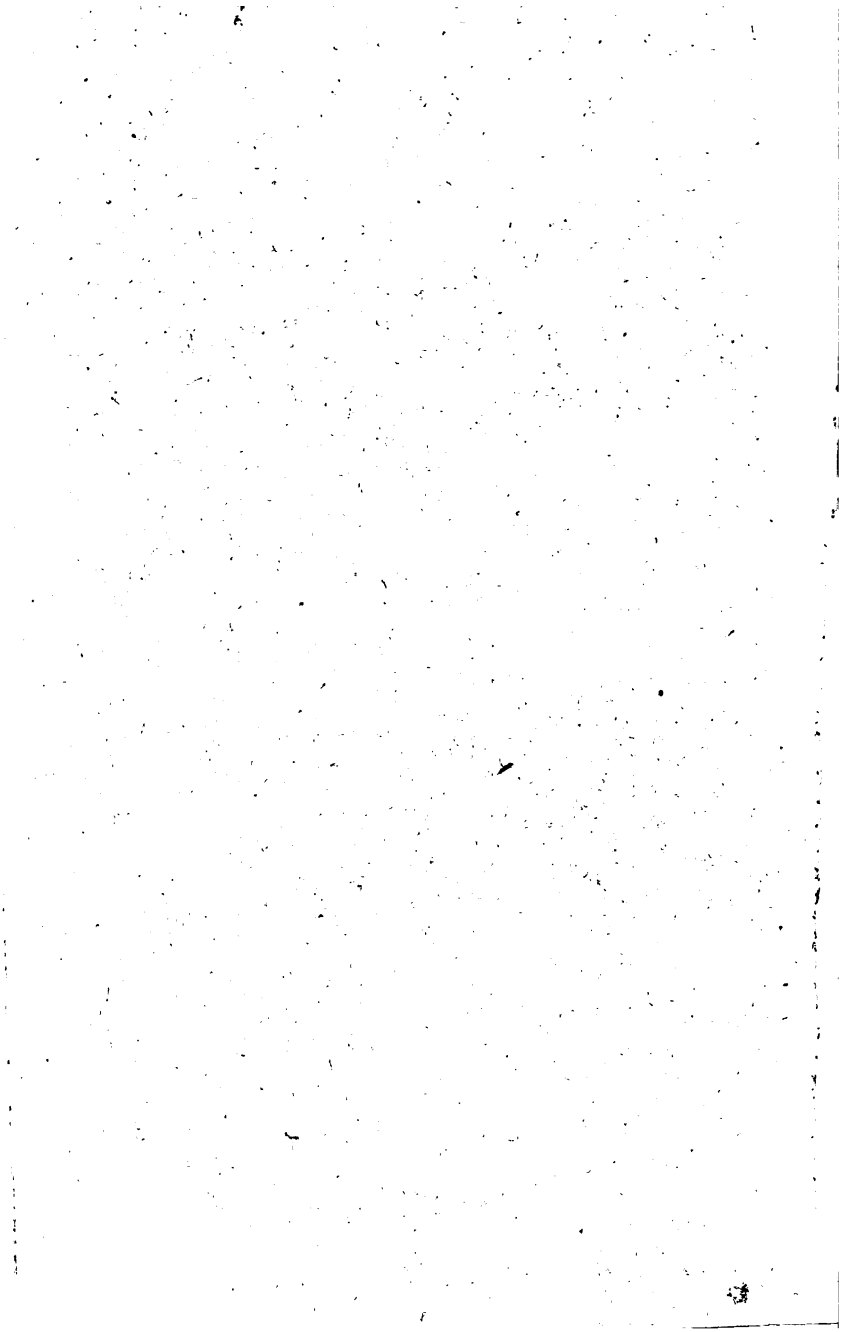

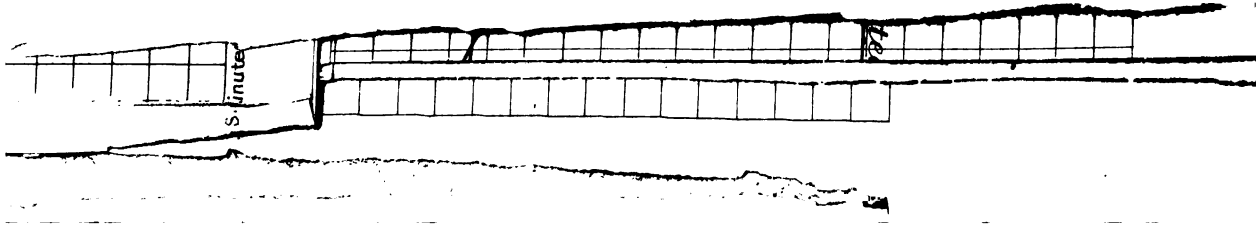
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THE

MECHANICAL AND OTHER PROPERTIES

OF

IRON AND STEEL

IN CONNECTION WITH THEIR CHEMICAL COMPOSITION.

BY

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1891.

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TO

Mr. R. A. HADFIELD,

ENGINEER OF THE HADFIELD STEEL FOUNDRY COMPANY, SHEFFIELD,

THIS WORK

IS RESPECTFULLY INSCRIBED BY

THE AUTHOR.

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THE

PROPERTIES OF IRON AND STEEL

IN CONNECTION WITH THEIR

CHEMICAL COMPOSITION.

INTRODUCTION.

THE object in view in preparing this work was to give a brief outline of the actual knowledge on the subject. It has been gathered from the widely scattered information upon the now generally acknowledged intimate connection that exists between the properties of steel and iron and their chemical composition.

It was considered best to treat the matter under heads, each dealing with one element at the time; however, as the different elements at times greatly influence one another, they often had to be considered simultaneously. In general, the following rule has been followed,—first, to say a few words on the metallurgical behaviour of the elements in question; next, to deal with their influence on pig iron, cast iron, wrought iron, and steel; lastly, to set forth the special uses made of them, and their occurrence in manufactured objects.

In order to avoid misunderstandings it will be best first to say how certain words are to be taken. After the English and French custom, the term steel is applied to all malleable iron obtained in the fluid state; thus including the softest kinds which are quite unhardenable, or, as it is sometimes wrongly said, which cannot be tempered. The difference between hardening and tempering should not be lost sight of: to *harden* steel is to suddenly cool it from a bright heat to a much lower temperature; whereas *tempering* is reheating when previously hardened to a certain point, then suddenly cooling again to fix the hardness of that moment. Annealing is of course slow cooling. It is obvious that a steel cannot be tempered unless it be first hardened; yet many use the word tempered instead of hardened, although this absurdity has more than once been pointed out.

There is no necessity for repeating the well-known definitions of tenacity, elasticity, &c.

In all the following cases figures for strength are given in kilogrammes per square millimetre, and elongation taken on 200 mm., unless the contrary be stated.* It was not considered of any value to give more than one decimal, firstly, because there exist such a quantity of inexpressible functions that influence such figures (such as: kind of testing

* The reason why I chose these figures instead of tons per square inch, commonly used in England, was that on the Continent kg. per sq. mm. are employed, and comparative figures should be given in the standard denominations. 1 kg. per sq. mm. is nearly equal to 0·635 tons per sq. inch.

machine, mode of testing, mode of clutching the test-bar, manner of applying the loads, manufacture of test-bar, dimensions, form, &c.) that comparative figures really ought not to be expressed in decimals at all; secondly, because it is of so very little interest to know whether, for example, the elastic limit (after all it is impossible to give it in a *certain* value) lies at say 30 kg. or at 30·1. It is of no practical use to give these decimals, it only takes more space and printing ink, and whole numbers are much easier to remember.

The same thing is done with the analyses figures, first again because the influence of 0·01 per cent. of anything is hardly known, secondly because so very few analyses are reliable even in their first decimal.

So much the more absurd is it to express contents of phosphorus or silicon, for example, to a third, say even to a fourth decimal. There is no difficulty whatever in giving still more decimals if only one has patience in calculating, but it is trying to give a deceptive appearance of exactitude. No one needs—really *needs*—to know phosphorus contents in ten-thousandths per cent.

To begin with the most important element, we shall start with carbon.

CARBON (C).

Metallurgical Behaviour.

The affinity of iron for carbon is so great that all technically produced iron invariably contains carbon, although it may be that the amount can be brought down to a few hundredths per cent. Notwithstanding this great affinity the limit of saturation (with ordinary iron) is arrived at with 4·6 per cent.—perhaps 5 per cent. for solid iron. In the fluid state iron may have much more carbon, but no definite figures are known for it. Fluid iron that contains more carbon than the above-mentioned limit will, on solidification, have part of it separated, and very rich iron will give rise to formation of kish when it becomes cooled down.

In order to unite carbon and iron it is not necessary that the iron be in the fluid state; when bar iron is heated sufficiently long at a high heat in a medium of carbon it will take up carbon and become converted into what is called blister steel. By this process, called cementation, 1 to 1·2 per cent. of carbon may be imparted to the iron.

Similar to this is the process of manufacturing malleable cast iron. Here the reverse takes place, an iron rich in carbon is heated up in an oxidising medium (iron oxides, such as purple ore or magnetic ore, or zinc oxide, &c.) and the result is an iron poor in carbon; thus carbon and, under some circum-

stances, CO are capable of moving intermolecularly into iron.*

In the blast furnace, when iron and carbon are face to face with one another, the iron will get saturated with carbon according to circumstances. The ratio of fuel and ore of course, in the first place, influences the amount of carbon taken up by the iron; the more fuel (carbon) in excess, the richer in carbon will the resulting iron be. It also depends greatly on the temperature in the furnace; the higher the temperature the more carbon will be absorbed, and the slower the furnace runs the more carbon will pass into the iron.

We see these two laws illustrated by the facts that when there is little fuel and the furnace cools down white iron is the result, and the output of mottled iron will be greater for a day's work than when grey iron is wanted. Taking a day's work = 100 tons for white iron, it will be 65 tons for grey iron rich in silicon, 60 tons for 10 per cent. spiegel-iron, 40 tons for rich spiegel, and 25 tons for 60 per cent. ferromanganese.

If a very rich iron is desired it can be obtained by raising the temperature of the blast and by putting more fuel in the burden. Attention however has to be given to the fact that a higher temperature also causes more silicon to be reduced, and as this element lessens the affinity of iron for carbon, it is

* Fleitman discovered similar intermolecular moving of iron itself, when a steel plate and a nickel plate were pressed together and heated.

necessary to keep the cinder as low in silicon as possible.

One of the reasons why the iron-smelters of Sweden have not gone in for very hot blast (they continue using iron pipe stoves if they heat the blast at all) is that their forge iron has to be white and as low in silicon as possible.

If the pig iron is to be remelted for foundry purposes it is clear that in a reverberatory furnace it will lose more carbon than in a cupola where there is carbon in contact with it. The alteration the amount of carbon undergoes in a cupola is not very important, it may increase, it may decrease, there are analyses of both cases; in a reverberatory furnace there is always a slight loss in carbon, but the reverberatory furnace, the efficiency of which is much less than for shaft furnaces, is only used in special cases.

In Sweden direct casting from the blast furnace is a rule; however, as these are very small (smelting only 5 to 20 tons a day) and charcoal being less appropriate for a cupola, the pig iron is often remelted in a reverberatory furnace. The well-known gun foundry of Finspong used to melt the pig for guns in reverberatory furnaces.

In refining processes in low hearth or refining furnace the carbon is slow to burn away, on account of the low temperature, the affinity of carbon for oxygen being a variable function of the temperature, and the temperature at which these processes are worked being low, it is easy to understand that they take a long time.

In the puddling process the carbon goes somewhat quicker, but still there remains a most marked difference in carbon disappearing diagrams of these processes and for the Bessemer process.

That the carbon does not burn away too soon in a puddle furnace is a fortunate thing because it keeps the puddler's bath fluid whilst he is removing the other ingredients.

The burning of the carbon in the Bessemer process is largely dependent on the temperature of the charge. When the initial temperature is low no carbon will burn before the greater part of the silicon has been oxidised, and the diagram showns an apparent increase. The more the silicon burns away the higher the temperature becomes; thus in the second or boiling period the carbon is attacked by the oxygen. When however the initial temperature is high the carbon will commence burning in the first moments of the blow, thus shortening the time of blowing.

In ordinary Bessemer practice the pig is only melted, not overheated, and contains 1·5–2 per cent. silicon, the carbon being 3–3·5 per cent. and the process of converting takes about 20 minutes.

Recent practice in America is to convert pig with only 0·7 per cent. silicon and 3·4 per cent. carbon. With so little silicon the process would be impossible were it not that the initial temperature is high and the blows very quickly succeeding one another, so that the vessel remains hotter, the duration of the blow being only about 8 minutes.

The same practice is followed in a Russian foundry. The initial temperature is about 1500° C. and the pig to be converted contains no more than about 0·8 per cent. silicon; duration about 14 minutes.

That in the open hearth process the decarbonisation takes such a long time, notwithstanding the very high temperature of the bath, must be attributed to the relatively little opportunity the carbon has to become oxidised, seeing that it is the oxides of the covering slag that have to fulfil this duty.

In broad outlines the characteristic elements of the different Bessemer practices are as follows:—

English Bessemer pig is generally pretty rich in silicon, not so much manganese and not overheated; hence at first an apparent increase in carbon. German Bessemer pig is generally lower in silicon but higher in manganese and is worked at a higher initial heat; hence a much more rapid fall of the carbon curve.

Swedish practice, recently followed in America and Russia, is to take a pig low in silicon, low in manganese, higher in carbon, and well overheated; hence a very rapid conversion into steel. The open hearth process, the diagram of which is partly given, was a Swedish pig and ore process and much quicker than it generally is (when using no scrap, but ore only, the process commonly lasts about 10 hours).

In the crucible steel process the change in carbon contents depends on the nature of the crucible material. When clay crucibles are used there is a decided loss in the carbon; it reduces the manganese

oxides of the charge. When however coke is put into the clay mixture, as is often done, the carbon of the steel is increased instead of decreased. When melted in a plumbago crucible a great deal of carbon is taken up by the steel, and nothing is less true than the old view that steel did not alter its composition when melted in a crucible.

Influence of Carbon on Pig Iron.

As is known, the carbon shows itself in two * different forms in pig iron i. e. the graphitic and the combined form. For the sake of convenience these may be denominated respectively β carbon and α carbon.

The ratio between these two, more than the total quantity, determines the quality of the pig: thus, for example, the difference in total carbon for hematite pig No. I. and ditto white may be 0·8 carbon. Whilst No. I. has say 0·1 α carbon and 3·8 β carbon, on the contrary, the white may have 3·1 α carbon and a trace β carbon.

As before said, different blast furnace conditions give different carbon amounts in the pig, hence No. I. pig is richer than the white, having been made at a much higher temperature.

In the total amount of carbon there are no great fluctuations, and a pig with a total carbon of about 3·5 per cent. will do for anything, provided its cha-

* Perhaps in three or even four forms; for our subject, however, the distinction of two forms is sufficient.

racter is suitable for the purpose. Thus, for example, Cleveland foundry pig (No. III.) has about 3·5 per cent. carbon; Cleveland forge pig about 3·3; French puddle pig about 3·2; basic pig about 3·5; Bessemer pig about 3·5.

What actually determines the grade of the pig is the ratio between α carbon and β carbon (not always however, because the grade is fixed by the appearance of the fracture, and the structure being dependent on many other things besides α carbon $-$ β carbon, the classification will often be incorrect). Now that ratio may be such that either α carbon or β carbon is nearly nil, and many varieties may be thus obtained. In glazed pig nearly all the carbon is as β carbon; on the other hand, in white pig nearly all the carbon is as α carbon; and yet in both cases the total carbon may be nearly equal.

That the total carbon of glazed pig and white pig can be the same although the first is obtained at a much higher temperature, seems in contradiction to former statements. This, however, is not the case. The apparent deviation is caused by the great difference in the silicon, glazed pig having about 6·5 per cent. of this element against 0·8 per cent. for the white, and as we shall see later on, silicon diminishes the affinity for carbon. Combined carbon imparts fluidity to the iron and makes it much easier to melt, this latter property being very marked. Assuming the melting temperature of cast iron to be 1100° C. and of extra mild steel to be 1900° C. then $3 \cdot 1 - 0 \cdot 1 = 3$ per cent. carbon causes a

difference of 1900° − 1100° = 800° C. in the melting-point.*

The richer the pig the more liability to separation of β carbon on solidifying.

Evidently fluid iron contains only combined carbon, because if it did contain β carbon this would come to the surface, being specifically lighter than iron.

The formation of kish is due to the fact that the hotter the iron the more carbon it can contain. Hence, when cooling the excess of carbon must go out of it, and being lighter it comes to the surface of the bath.

The separation of β carbon causes the grain of the pig to be coarse, and, generally speaking, the more β carbon the coarser the grain. Rapid cooling prevents the separation of β carbon more or less, and if not too rich and not containing much silicon the pig may be made to contain only traces of β carbon when solidified suddenly.

Forge pig, which has to be white and low in silicon, and therefore smelted at a low temperature, is generally cast in iron moulds and the β carbon seldom exceeds 1–1·5 per cent. As to the mechanical properties of pig iron, these are of little importance as pig is seldom used for castings. Direct casting from the blast furnace can be done at charcoal furnaces, but even then remelting is often preferred or necessitated.

* I do not mean to say that cast iron contains 3·1 per cent. α carbon, but that the moment before melting the β carbon is transformed into α carbon. β carbon as such would only in a slight degree influence the melting-point. It may perhaps be that the lesser compactness of grey iron will favour the melting.

Influence of Carbon on Cast Iron.

As in the case of pig iron, the total carbon is of far less importance than the ratio between the α carbon and β carbon. Castings may be divided into ordinary castings and special castings; among the latter we place chilled iron castings.

Graphitic carbon, as such, of course has no influence, as it no longer belongs to the iron but being intercalated between the iron molecules it disturbs continuity and homogeneity and thus weakens the whole. On the other hand it forms an elastic medium, thus imparting more elasticity to the iron. An indirect result is that it makes the iron softer, because the total amount of carbon remaining the same, the more β carbon, the less α carbon there can be.

The structure of cast iron depends greatly upon the β carbon. Speaking generally, the structure will be the coarser, the more β carbon, and a too coarse structure not being wanted in castings not too much β carbon should be present, hence the desirability of not cooling too slowly, i. e. not pouring too hot.

Large masses naturally cool slowly, hence they show a coarser grain than small pieces. There is less difficulty in preventing small castings from becoming white by too rapid cooling, than there is in preventing large castings from becoming too coarse.

The amount of β carbon is a most valuable means

of regulating the strength of castings, although its influence is only indirect. Too little β carbon causes too much brittleness and hardness; too much of it causes weakness. How much of it is wanted to obtain the desired result depends on the size of the object, and no fixed limits can be given. The thinner the object, the more silicon must be present in order to obtain the requisite quantum of β carbon.

It is obvious of what great importance physical conditions are in dealing with cast iron; these combined with certain chemical conditions will give any kind of casting. Chemical conditions to obtain a suitable amount of β carbon are, in the first place, presence of silicon and absence of manganese; in the second, absence of sulphur.

Quite recently the most remarkable fact was made known that aluminium in cast iron tends to produce soft castings, and not only that even the thinnest parts will be grey, but rapid cooling actually causes the β carbon to be separated in a finer state. If true this would be a most favourable circumstance.

In white or chilled castings it is just the α carbon which plays the most important rôle. In order to obtain a casting that, when rapidly cooled (cast into iron or wet sand moulds) will be white, it is necessary that the total carbon be not too high (the larger the casting the lower the total carbon must be), and invariably the silicon must be low, unless the manganese be high enough to neutralise it.

Low total carbon and low silicon being desiderata

has led to the opinion that cold blast pig gave a better chill than hot blast. Cold blast pig contains less carbon and less silicon than hot blast, thus it is evident that it is more suitable for good chilled castings: but the real cause should not be lost sight of. As said above, manganese and in less degree sulphur tend to keep the carbon as *a* carbon; a certain quantity, up to 2 per cent., of manganese is often necessary in order to obtain a good chill in the casting when rapidly cooled.

It is said that white iron contains more sulphur than grey; this may be due to the fact that the temperature of formation was lower and consequently more sulphur taken up (see Sulphur); but it may be also that the cause lies the other way, i. e. that because of the presence of sulphur the iron becomes white, and this is the more probable. Purposely adding sulphur to cast iron has been a rule in the gun foundry of Finspong and a stronger casting has been obtained in this way because there was more *a* carbon in it.

It is evident that a body so complex as cast iron does not readily lend itself to a consideration of the influence of carbon on its strength, the other constituents making out such a great deal of it.

In general we may assume that *a* carbon gives high crushing strength, high tensile strength, but brittleness at the same time; it imparts hardness to such a degree that good chilled iron is unworkable by ordinary steel tools and either special steel tools or emery wheels have to give the finishing touches.

The maximum hardness is obtained with 2 per cent. = *a* carbon. Graphitic carbon, on the other hand, gives a good working property; the metal is soft, it decreases tenacity on account of its disturbing continuity, but at the same time forming an elastic medium lessens the brittleness.

According to the predominance of *a* carbon or *β* carbon the first or the second named properties will prevail, and by a skilful choice of composition cast iron can be made to fulfil many requirements. Transverse strength, being a combination of tensile and crushing strength, will be highest at a medium amount of *a* carbon and *β* carbon. Combined carbon gives a good resistance to impact. Cast iron has a very low modulus of elasticity and is said to show no limit of elasticity; at all events if it has one it lies very low, and not being tough either, the sole property which gives it value for girders for small bridges, framework, &c., is its stiffness. The high resistance to compression renders it very useful as a metal for columns.

White iron is also extensively used in chemical industry for boiling-pans for concentrating, &c., sulphuric acid, nitric acid, &c.

Influence of Carbon on Wrought Iron.

The quantity of carbon present in wrought iron is but small, consequently its influence is insignificant.

Bar iron from low hearth or puddle furnace contains 0·05–0·10 per cent. carbon, and it matters

very little indeed if this is 0·01 per cent. more or less. Such iron is fibrous, not strong, but extraordinarily ductile, and tough in the direction of its fibre. Across the fibre the strength is very much less, only $\frac{1}{2}$ or $\frac{1}{3}$ of the former. Its use is chiefly in the blacksmith's shop where it is highly appreciated for its good forging and welding qualities.

Less fibrous and stronger is the fine grained or steely iron. It is not so ductile but varies less in strength lengthwise and crosswise, and is more suited for general use.

Of far more importance is the

Influence of Carbon on Steel.

The effect of carbon on steel is pretty well known, though it is possible there still remain a good many things to be settled about it. The first difficulty we come across is the fact that in steels carbon occurs in different forms. It will be as well to say a few words about these.

We considered only two forms of carbon in pig iron (because not much more is known with certainty); now in the case of steel the combined carbon probably occurs in two distinct forms,—one prevailing in blister or cement steel and therefore called cement carbon; another chiefly showing itself in hardened steel, therefore denominated hardening carbon. Cement carbon, later on christened "carbid" carbon because it exists in steel as a carbide of iron, Fe_3C, is the more common of the two, hardening

carbon only being in larger quantities in hardened steel. Whether this latter is not also a carbide but of the formula Fe_4C is not yet made out for certain. While, thanks to thorough investigations, the connection between these carbon forms and physical and mechanical influences such as change of temperature, work, pressure, &c., are pretty well established, on the contrary the influence of chemical changes is unfortunately as yet next to unknown. If in the following considerations mention is made of carbon only, it is because the knowledge concerning the different carbon forms and their influence on the mechanical properties is very limited, and we may be sure many of the anomalies felt on comparing theoretical considerations and practical results are to be attributed to our not distinguishing between carbid and hardening carbon.

The influence of carbon on the properties of steel is very marked—in fact it is the most handy and reliable ingredient because by altering its quantity one is able to produce almost any kind of metal wanted, provided no impossibilities are asked.

Between the limits of tenacity there is a wide space for employment, from the softest boiler-plate steel to the hardest tool steel.

Most remarkable is the marriage between tenacity and hardness which ever go hand in hand (in the case of carbon steels).

The tensile strength of steel is directly variable with its carbon content. If the breaking loads are et out as ordinates and the contents of carbon as

abscissæ, then the line uniting corresponding points is nearly a straight one. For pure carbon steels, that is steels in which carbon forms the chief constituent, and in which only minor quantities of other elements are present, it may be said that each 0·1 per cent. carbon more or less increases or decreases the ultimate strength by about 6 kg. per sq. mm. A maximum of strength is obtained at about 1 per cent.

Besides increasing the tensile strength, carbon causes a rise in the elastic limit, and here we see a decided influence of hardening carbon, as by increasing the amount of hardening carbon e. g. by sudden cooling from a bright heat, the elastic limit may be raised so as to be nearly at the same point as the ultimate strength.

In the case of so-called dead hard steel there is, practically taken, no difference, so that this kind of steel shows the maximum of brittleness, its non-elastic elongation being about nil.

As to the modulus of elasticity, some hold this to have a constant value for any kind of steel. Not only do recent investigations with more accurate testing machines show the falsity of this view but such an assumption is contrary to reason.

There is as much (or as little, as you please) essential difference (as regards elasticity) between the two extremes of steel kinds as there is between steel and any other metal or material. Why should then the modulus of elasticity be a constant? there exists no reasonable ground for it (that both bear

the same name cannot very well have anything to do with it); and if on account of the great difficulties encountered in measuring elastic elongations this has been done imperfectly and shown a quasi-constant value of the modulus it cannot be affirmed any longer, now that different values have been actually obtained by careful experimenters. As to the connection between the carbon content and the modulus no definite figures are known yet; it seems that a medium hard steel has the highest modulus of elasticity.

In ordinary circumstances the elastic limit is 45–55 per cent. of the ultimate strength. Graphically drawn they are seen to be non-parallel curves, having a cutting point falling beyond the y axis, which means that for low carbon steels the elastic limit is nearer the ultimate strength than for high carbon steels. That by suitable hardening, tempering, and annealing processes the elastic limit and ultimate strength may so to say be varied at our will is a fortunate circumstance, because not only is the elastic limit a decisive point in the choice of a steel but also its distance from the ultimate strength.

Whether carbon has any influence on the so-called second elastic limit is at present quite uncertain. The crushing strength of steel is not much superior to that of cast iron; there are cast irons showing a higher figure for crushing strength than even hard steel. There is a larger play in the tensile strength of steels, which runs from about 35 kg. to about 120 kg.

(or even to 300 kg. in special cases), than there is in the crushing strength, which runs from about 50 kg. to about 130 kg.

Steel is evidently not called upon to supersede cast iron where only a compressing strain is applied, because for cast iron about 75 kg. may easily be obtained.

Steel possessing a much higher crushing strength than wrought iron, it is consequently better suited for structural work where its transverse strength comes into play, this being of very great importance when considering the preference to be given to steel versus wrought iron for bridge girders.

Steel being more rigid than wrought iron, an equal strain will cause a smaller deflection in the first (when tested for transverse strength), but, for example, in a bridge girder, steel being strained a good deal more than wrought iron (10–15 kg. per sq. mm. for the first, 6–8 kg. for the second), the first when fully loaded will show a larger deflection than the other; the maximum elastic elongation being for steel larger than for iron. The non-elastic elongation is what is determined by ductility, a very tough metal has a large non-elastic elongation.

The less carbon—that is the milder the steel—the larger the elongation. It may reach 40 per cent. on 200 mm. for the mildest steel* gradually to diminish to a few per cents. for the hardest class.

* A suddenly fractured test piece may occasionly show an elongation of over 70 per cent.

Increase in carbon involves decrease in ductility, and each augmentation of carbon 0·1 per cent. approximately causes a fall in the figure for elongation of 4 per cent.

The difference of elongation when measured on 100 or 200 mm. is larger for soft steels than for hard steels, and invariably the higher figure is obtained when measured on the shorter test-piece.

But elongation is not the only measure for ductility, contraction of area is also one, and the same rule stands here: the higher the carbon the less contraction. Indeed contraction is a disagreeable property because it gives false results of tenacity.

The high figures for hard steels are to a great extent due to the fact that the load applied always remains to be taken up by one and the same section (nearly so), that is always by nearly the same number of molecules whose coherent force counterbalances the tensile stress. A great contraction and small elongation is a bad sign of local yielding; when, however, both are great it is a good sign of homogeneity; but evidently in the latter case the total contraction must be less than in the former. For this reason, I cannot share the opinion of some, that contraction is the better measurement for ductility.

A large contraction implies low tensile strength. The absence of toughness in harder steels is a serious drawback to their employment in structural steel because even with a sufficient margin of safety the chance of sudden snapping off is too much to be feared.

As to vibrations, it is well known that medium hard steel stands them a good deal better than softer kinds; but this question remains to be settled yet, practical results not corresponding with experiments.

Tempered steel (such as a spring for instance) will certainly stand any amount of vibration, but as to mild steel, many unexplained sudden failures have occurred, and the fracture always being quite crystalline, they were attributed to change of structure by vibration.

Authoritative experimenters have shown that a strain below the elastic limit, even if repeated a million times, does not alter the structure.*

The fact that sudden rupture changes the aspect of the fracture † has led to the wrong assumption that change of structure had caused the rupture.

The higher the carbon the better resistance to impact. Hard steel does not set up, which is very valuable in the case of steel shot.

Leaving these mechanical properties we may say a few words upon some physical ones.

* We all know that the small spring of a watch, making 150 double bendings a minute, has been bent 78·84 million times in a year; assuming a life of a century, it will have been subjected to a round 7884 millions of double bendings without becoming visibly altered.

† A wrought-iron chain link for example, when torn asunder, will show on one side a fibrous fracture, but a granular one on the other, because the one that is fractured latest is fractured with great excess of power, that is, suddenly.

In the first place comes the most remarkable property of taking temper when suddenly cooled from a visible heat (anything above 600° C.) to ordinary temperature. The higher in carbon it is, the harder the steel will be after the hardening,* the maximum value lying at about 1·5 per cent. carbon and commencing to be visible with about 0·3 per cent. carbon, although even in case of only 0·1 per cent. carbon the metal shows increase of strength, decrease of ductility, but there not being a perceptible increase in hardness it was formerly thought that quenching had no influence on such low steels. When containing under 0·15 per cent. carbon a test-bar may be bent double after having been quenched.

The natural hardness of steel—that is the hardness it possesses in the unhardened state—is greatest at about 2 per cent. carbon. The working properties, i. e. for rolling and forging, decrease rapidly with increase in carbon ; welding especially becomes difficult, and occasionally impossible.

Hard steel does not stand in the fire, it has a tendency to lose carbon and to burn, that is, some of the iron gets oxidised and the iron oxide interposing itself between the steel molecules destroys the quality ; thirdly it assumes a coarse crystalline structure which makes it unfit for anything.

Thus hard steels have to be handled very carefully ;

* Every grade of steel has its own temperature of greatest hardness ; the harder the steel the lower that temperature ; when heated more and quenched subsequently the steel is less hard than if quenched at its proper temperature.

the harder the steel, the sooner it becomes overheated and deteriorated.

The marked influence of carbon on the melting-point has given rise to curious expressions. Thus in former times only hard steel could be melted and "cast steel" meant a hard steel; nowadays nearly all steel has been cast (either in moulds or in ingots) and any grade can be made fluid, although it takes a good deal more heat to melt very mild steel than hard steel. For a long time wrought iron was considered to be unmeltable, and no small surprise was caused when Sir Henry Bessemer showed that he had melted steel with a few hundredths of a per cent. carbon without fuel (silicon is no fuel in the proper meaning of the word) and cast it. Even in recent books of engineering we often meet the word "cast steel" in that ancient meaning of crucible steel.

Carbon has also a decided influence on magnetic properties. Very soft steel has less susceptibility and less retentiveness of magnetism. Both have their maximum value with the hardest steels, and here again the hardening carbon seems to play the most important part, especially on the retentiveness, dead hard steel being most suited for permanent magnets. The density is higher for mild steel than for hard steel. Lastly it may be mentioned that increase in carbon diminishes liability to corrosion.

We must remind the reader that in most cases not only carbon but also manganese, silicon, phosphorus, sulphur, occasionally chromium, tungsten, and other elements are present, and the different influences of

those constituents may well annihilate or amplify one another or call forth new properties thereby causing very complex results. The quality of steel can very seldom be judged from one constituent element, as it is very seldom free from other ingredients.

Uses and Occurrence.

Special alloys of iron and carbon only have, as far as we know, never come into any use, nor are likely ever to do so, and the rich pigs are valued not for their contents of carbon. On the contrary the use of iron (Fe) low in carbon far exceeds the use of iron high in carbon: we mention wrought iron and mild steel for the first, cast iron and hard steel for the second.

Wrought iron is especially appreciated for its toughness and high forging qualities; hence if these properties are wanted the lower the carbon the better.

Swedish Lancashire iron hardly contains above 0·05 per cent. carbon and, being nearly free from other ingredients, has a well-deserved world-wide reputation. Chain links, for whose manufacture a very good welding quality is a necessity, are advantageously made of such soft iron.

Puddle iron generally has a little more carbon, say 0·07–0·10 when it has to be very fibrous.

The fine-grained or steely iron formerly used for the head of a rail, being harder, contains 0·2–0·3

per cent. carbon. It is largely used for nails, wire, axles, rivets, &c.

Puddle steel containing 0·6–0·9 per cent. carbon is sometimes, or rather was, used for hoops for built-up guns; however its destiny principally is to be melted and to form the basis of crucible steel in larger quantities.

As said before, by heating iron in a medium of carbon a cementation, i. e. carburation will take place and after a prolonged heating at a high temperature blister steel is obtained which serves as a raw material for crucible steel of the highest class.

The same process is sometimes used to impart a hard surface to some objects, they are then called case-hardened. Crossheads, bearings, slide-bars, &c., were given a better wearing surface, or smaller objects, keys, &c., to give them a better appearance as they take a better polish; however the use of cast steel more and more supersedes most of these old methods.

It may seem wonderful indeed that puddled steel is used at all in its manufactured state, not having the advantage of puddled iron, toughness, nor that of cast steel, strength, but instead the inconvenience of non-homogeneity, irregularity, and local weakness on account of the welding. It was for a time extensively used in the construction of British guns, the older types of which all show an enormous thickness of metal.

Ordinary *cast iron* still holds its own on account of

many advantages, as cheapness, ease of manipulation, fair strength, &c. Thus for compression members such as columns, bed-plates, also for the framework of engines, machine tools, &c., it is valued, being as good as steel and much cheaper. For gun construction it is theoretically so utterly unadapted that it cannot but surprise us to hear that even now cast-iron guns are being constructed—though reinforced by steel.

France, Spain, and other countries employ cast-iron guns for cheapness' sake. The chief element in a gun-metal is elasticity, just the very thing nearly absent in cast iron, or at all events not by a long way what it is for steel. The low efficiency per ton of gun for cast-iron guns plainly shows the correctness of this view.

American gun iron has 0·8–1·78 per cent. α carbon and 2·83–2·00 per cent. β carbon; Swedish (Åker) ditto, 1·4 per cent. α carbon, 2·5 per cent. β carbon; the well-known Finspong iron 0·8–1·4 per cent. α carbon, 2·4–1·8 per cent. β carbon; Woolwich, 0·9 per cent. α carbon, 3·6 per cent. β carbon.

Cast iron admits of comparatively large differences in composition and no fixed figures can be given, the constituents being so many and of so varying a character.

More interesting is the use of *chilled iron castings* for railway tires, rolls, shells, armour turrets, railway crossings, pulverisators, &c. As before stated, in a chilled iron casting the greater part of the carbon is

kept in the combined state. To obtain this result it is not enough to cast in iron moulds (or wet sand), certain chemical conditions have to be fulfilled also.

The highest crushing strength is met with at about 1 per cent. *a* carbon and 2·6 per cent. *β* carbon, giving a total of about 3·6 per cent. Rolls may have 2·7–3 per cent. carbon, whereof about 0·8 per cent. *a* carbon; tires 3–3·7 per cent. carbon, whereof 0·7–1·5 per cent. *a* carbon (American tires, with a deepness of chill of 15 mm. on 60 mm. diameter). Palliser shells, 2·8–3 per cent. carbon, either chilled over the whole body (Grüson) or only in the head (Finspong).

Armour plates as made by Grüson and perfected by him to such a degree, contain 3–3·3 per cent. carbon, and may show a chill of 40 mm. on a thickness of 500–1000 mm.; however, the deepness of chill depends on the position of the plate in the turrets (front plates deepest, top plates less). Grüson's famous chilled cast iron holds on average 0·5–1·2 per cent. *a* carbon and 2·3–2·9 per cent. *β* carbon, and according to its use for armour plates, shells, rolls, tires, crossings, anvil-blocks, &c., the *a* carbon is varied between those limits.*

Steel.

Mild steel such as is suitable for boiler plates, ship plates, angle and other structural steel for

* At my request Mr. Grüson had the goodness to have made an average analysis of his chilled cast iron, for which kindness I most sincerely thank him.

bridges, roofs, rivets, &c., seldom contains more than 0·3 per cent. carbon, as mostly about 20 per cent. elongation is required with an ultimate strength of 40–50 kg. per sq. mm., besides cold bending and non-hardening test, this being the condition for boiler and ship plates by the English, French, and German Navy, Board of Trade, Lloyd, and others. Plate and other steel for bridge work is sometimes preferred to be somewhat stronger, at all events nearer the 50 kg. In Holland, a metal of 60 kg. was found to be better than either softer or harder.

In the case of 60 kg. the carbon has to be about 0·6 per cent., or manganese has to help, in which case the carbon may be the lower the more manganese is put into it.

Most of the bridge steels, however, show about 0·2 per cent. carbon (Forth Bridge, Obouchoff bridge steel, Motala bridge steel) or even less, 0·07 for example (Kladno in Austria).

The very mild steels having 0·1 per cent. carbon or less are more easily obtained by the basic process than by the ordinary or acid process of steel-making.

At the Cockerill works in Seraing ship plates are made with 0·08–0·15 per cent. carbon, angle steel with 0·04–0·09 per cent. carbon.

Wire rope for haulage generally contains 0·15–0·3 per cent. carbon unless a special hard kind is ordered; chains also have about 0·2–0·25 per cent. carbon. The hardest wire seldom more than 0·65 per cent. carbon.

For ordnance material generally a harder and

stronger kind of steel is used, although some prefer a mild steel for guns: e. g. Terre Noire, 0·12 per cent. carbon; Cammell, 0·14–0·19; Vickers, 0·24–0·27; Trubia (Spain), 0·23–0·33.

Harder steels are, Firth, 0·34–0·4 per cent. carbon; Whitworth, 0·3–0·42; Bofors, 0·35–0·45; (cast without blowholes); Witten, 0·47; Krupp, 0·45–0·71; also Terre Noire, 0·5–0·88 (cast without blowholes).

A modern gun being built up of different parts which have to fulfil different duties must not be made of one and the same steel unless different mechanical properties are obtained by different processes of hardening, tempering, &c.

The law of increasing rigidity (wrongly called sometimes the law of increasing elasticity), that is the law that each succeeding layer of reinforcement shall have a higher modulus of elasticity than the preceding one, is not yet followed by all gun-makers, as it is rather difficult to do so as long as we ignore the integral conditions that govern rigidity. However, it is not here the place to enter into details about rational gun construction; thus merely alluding to the subject we must leave it and proceed.

Barrels for small arms show as great a variation in the carbon amount as big guns; thus those from Solingen contain only 0·13 per cent. carbon, whilst Terre Noire puts 0·3 in the steel; Spanish barrels contain 0·43; Witten, 0·47; St. Chamond, 0·49; Firminy, 0·57; Unieux, 0·60.

Armour plates also differ very much as they are made of two opposite kinds, i. e. so-called soft armour (wrought iron or very mild basic steel), which have to yield locally, containing 0·06–0·09 per cent. carbon, e. g. in Kolpino wrought-iron plates, Dillingen (wrought iron) with 0·04 per cent.; basic Bessemer plates, 0·08.

Against these stands the "hard armour" either in the form of compound, i. e. steel-faced plate, with 0·7 per cent. carbon for Cammell's plate, 0·65 for Brown's plate (Spezia trials, 1882), or as solid steel * as manufactured at Le Creuzot with 0·45 per cent. carbon (Spezia trials, 1882).

Steel shot is higher in carbon, having to be hard and elastic; it contains up to 1 per cent. (Krupp solid steel shot 0·88). For steel shrapnel, on the other hand, where the case has to be tough so as not to burst, but to hold together on explosion of the bursting charge, 0·3 per cent. carbon will suit the purpose when severe tests are required such as e. g. folding double together; when heavier bursting charges are used, 0·5 per cent. carbon will answer the purpose better; but of course these would not stand the same drop test.

Steel for machine parts either forged or cast without blowholes, seldom contains over 0·5 per cent. carbon, except for special purposes.

Bofors steel without blowholes for gun-carriages, propeller-blades, &c., is made with 0·3–0·5 per cent.

* A third kind of hard armour, viz. chilled cast iron, has been already mentioned.

carbon. Terre Noire steel without blowholes has about 0·5.

In rail steel there is not much variation in carbon contents. Krupp, Hoerde, Phœnix, Reschitza, Witkowitz, all give about 0·3; good rails in Finland, 0·3–0·4; Edgar Thomson rails, 0·3–0·4; North Eastern, 0·45. French rails however are sometimes of a much harder kind, containing even 0·85 per cent. (P.L.M. line).

Railway tires are of a harder class, and contain 0·6–0·9 so as to stand the wear and tear better (Bochum tire, 1·3). Railway axles contain about 0·5 per cent. carbon; in Sweden, however, 0·25–0·35 is preferred. Crossings and points are also made of hard steel; a crossing from Bochum contained 0·9 per cent. carbon.

There is no reason why shafting in factories should not be made of medium steel with say 0·5–0·6 per cent. carbon. Krupp's shaft steel has 0·3. It is probable that cold-rolled steel shafts do not contain more than 0·3.

The hardest class of steel is used chiefly for tools of all kinds. Tools show a very great variety in carbon contents and at the same time they are lowest in other elements. Tool steel seldom contains less than 0·5 per cent.; saw-blades, which have to withstand their setting, contain 0·5–0·6; cutlery work has about 0·6; the same for swords, scythes, and the like. For tools not requiring extreme hardness such as punches, cold chisels, &c., 0·7–0·8 will do very well, also for strong springs (railway

carriage springs and buffers). Watch and clock springs generally have less carbon, i. e. about 0·6 per cent.

Hammers are made of varying steel according to destiny, 0·5–0·7 per cent. carbon; anvil blocks about 0·7; milling tools are often made of a harder steel so as to require a less intense hardening, thus involving less risk of cracks. It is an acknowledged fact that it is better to take a steel of a greater natural hardness and give less hardening (heating to a lower temperature or tempering lower down) than to do the reverse. Milling tools often contain 0·85 per cent. carbon; the same for taps and dies, and twist drills. Coining dies contain 0·8–1·2; the first, a Dutch die, had stamped 200,000 coins, the Royal mint uses the harder kind. Razors also are made of very hard steel, 0·9 per cent. carbon and more. Turning and slotting steels may have 1–1·4 in order to keep edge, also files may have as much as for these. Good hardness and hardenability are first conditions to be fulfilled.

Permanent magnets are made of the hardest steel possible, involving great risk of cracking on hardening, in which the greatest care has to be taken as to equal heating and equal cooling; the first is best done in a muffle furnace, which, at the expenditure of an enormous quantity of fuel, gives a uniform heat throughout.

In the case of tool steels, the exact hardness, &c., being much more easily obtained by a proper hardening and tempering process, it is evident that the

carbon limits are wide. Finally I wish to point out that as the quality and properties of cast iron, wrought iron, or steel depend neither on the chemical composition alone nor on the carbon alone, it is evident that all the above figures give only an approximate idea of how much carbon generally may be found in different objects; but it is by no means intended to give ideal contents of carbon. This cannot be done at present, and in all likelihood never will be.

MANGANESE (Mn).

Metallurgical Behaviour.

The reduction of manganese oxides by carbon requires a very high temperature—a white heat; it is however greatly facilitated by the presence of iron. Tamm made crude manganese from pyrolusite; on smelting 1000 parts of the mineral containing 50·5 per cent. Mn, 3·5 per cent. Fe, he obtained 420 parts "cast manganese" as he calls it in analogy to cast iron, composed of 96·9 per cent. Mn, 1·05 Fe, 0·85 Si, 0·95 C, 0·05 P. After remelting with carbonate of manganese he found it to contain 99·9 per cent. Mn, 0·03 C, 0·05 Fe, 0·02 Si.

This experiment has scientific value only, as pure manganese obtained in this manner is altogether too costly and cannot be kept in the metallic state except

under cover of paraffin oil, because of its great affinity for oxygen.

Metallic manganese easily unites with carbon, silicon, phosphorus, sulphur, iron, aluminium, copper, chromium, tungsten, &c. In the above mentioned sample of manganese the low carbon is remarkable; generally crude manganese contains 6 per cent. or more.

On smelting a mixture of manganese oxide and silica with carbon, a crude manganese with about 10 per cent. silicon is obtained.

No alloy of manganese is of more importance than that with iron; its manufacture on a large scale has been one of the greatest steps in iron metallurgy. We do not consider it of any use to repeat the history of the manufacture of the so-called ferromanganese and spiegel-iron.

At the present time any manganese-iron alloy, up to those containing 90 per cent. manganese, can be obtained in the blast furnace, and we are much indebted to the Terre Noire Company for having pushed through all difficulties the production of rich ferromanganeses in that most powerful reduction apparatus, the blast furnace.

The difficulties to be surmounted in making these alloys are augmented with increase in manganese, and 80 per cent. may be put as a practical limit because the richer alloys are unsuitable and fall to pieces after a while.

The fortunate circumstance that the presence of iron greatly facilitates the reduction of manganese

oxide is counteracted by the undesired affinity for carbon, thus the richer the alloy the higher also the carbon, e.g.:—

Spiegel-iron,	10 to 20	per cent.	manganese	.. 5	per cent.	carbon.
Ferromanganese	35	„	„	.. 5·5	„	„
„	56	„	„	.. 6·	„	„
„	65	„	„	.. 6·5	„	„
„	80	„	„	.. 7	„	„
„	90	„	„	.. 7·3	„	„

The amount of fuel to be used for the manufacture of spiegels and ferromanganese increases rapidly with the percentage of manganese and may be said to average 1100–1250 kg. per ton spiegel, 1500–1800 kg. per ton rich spiegel, and 3000 kg. or more in case of ferromanganese. Besides this an enormous waste is involved by the facts that the cinder takes about 40–50 per cent. of the manganese of the burden; that the gases carry away something like 15 per cent. of it as a brown smoke because the reducing temperature is so near the volatilising temperature of manganese; and thirdly recovering the gases is seldom practised at ferromanganese blast furnaces because of the large amount of dust in them and high temperature at the throat (600°–700° C.) which no tubing would stand for long. The slag has to be basic or at the most a singulo-silicate (MnO not taken into account), and when the basicity is due to lime there is no necessity for a graphite lining to the hearth.

The necessity for a basic slag being at first overlooked caused the greater part of the manganese to

be scorified till the slag was basic enough, but then a manganiferous slag corrodes the lining of a furnace, hence the recommendation of a plumbago lining.

A high blast temperature and slow running are conditions to be fulfilled, and it will not surprise that under all these unfavourable circumstances the manufacture of rich ferromanganese is rather a costly business.

As will be seen in a later chapter it is just that awkward affinity for carbon of iron rich in manganese that has led to the production of ferromanganese wherein the percentage of carbon per unit of manganese is lowest, i. e. the rich brands.

Many iron ores, especially the spathic ones, contain manganese oxides and on melting will give a manganiferous pig the manganese grade of which depends on the above named circumstances (heat, basicity of cinder, &c.). Richer spiegels are obtained by mixing manganese ores in the burden, and of course, for the ferromanganeses, manganese ores are mixed with iron ore, or in the case of the highest grades contain just enough iron of themselves.

When the manganese ore used contains much phosphorus, which unfortunately is often the case, the phosphorus will do less harm in a very rich manganese pig than in a lower grade because of the former much less is used, consequently less phosphorus introduced in the steel. In all melting or oxidising processes manganese is a protecting element for carbon, or, in other words, manganese burns before

carbon in cupola and reverberatory furnace, in low hearth and puddling furnace.

In the Bessemer converter, where the temperature is so much higher, manganese and carbon burn fairly well at the same time till at the end when the temperature is very high, then carbon burns more. Also in the open hearth process, as might be anticipated, the manganese is oxidised quicker than the carbon.

In crucible steel making there is opportunity to observe how manganese of the charge and silicon of the crucible change places to a certain extent. To a crucible charge almost invariably some manganese is added in the form of oxide, not so much because manganese is wished in the resulting steel but on account of the already mentioned fact that manganese reduced by the carbon of the steel is a reduction agent for silicon from the pot, and it being this silicon that causes the killing of the steel, it was known long before any scientific explanation had been given to the fact that addition of manganese oxides greatly improves the quality of the steel.

Something similar takes place when in a cupola spiegel-iron is remelted, the manganese reduces silicon from the lining and the melted pig will be richer in silicon than the one charged.

Manganese in Pig Iron.

In foundry pig manganese is not a welcome element unless a metal for chilled castings is wanted. Some English foundry pigs contain more

manganese than could be desired, but as they are at the same time pretty rich in silicon they hold their own. To mention a few analyses, we have Coltness No. I. with 1·5 per cent. manganese; Langloan No. II., 1·2; Clarence No. III., 0·7; Cleveland No. III., 0·4; hematite, 0·3; Phœnix No. III., 0·9; Hoerde, 1·2; Terre Noire No. III., 1; Gutehoffnungshütte No. III., 0·2.

The more manganese present the more silicon and carbon must be present as well, in order that the casting shall be nice and soft; and as one and the same pig seldom fulfils all conditions, different pigs are mixed and melted together, often to the disadvantage of the manager when he is ignorant of the different compositions of his pigs and only works by rule of thumb.

One advantage of manganese in pig is that by its protecting carbon and silicon from oxidation the pig will stand remelting oftener—just the very thing English pigs have gained a reputation for. If not sufficiently rich in silicon too, a manganiferous pig will turn white when cast. For the manufacture of chilled castings a pig with 2 per cent. manganese is a desideratum.

The percentage of manganese in pig iron varying from very little to 80 per cent., it may be understood what a great number of grades may be made as regards manganese.

The specular structure of the 10–20 per cent. manganese grades is lost again in the richer brands the crystals become developed more lengthwise, i. e.

become needles instead of scales and are often splendidly coloured by surface tints.

Forge pigs such as are treated in low hearths generally contain little manganese, owing principally to the fact that a forge pig, having to be white, has to be made at a low temperature, and as we have said, the reduction of manganese requires a high temperature. Cleveland forge pig (white) has 0·6 per cent. manganese; Dowlais, 0·1; hematite, 0·1; Firminy, 0·1; Swedish pig, from trace to 1·8; Yorkshire, trace; &c.

In the puddling furnace manganese in the pig is valued for its protecting properties because the carbon may not disappear too soon, as the bath has to be kept fluid till the end of the process when it becomes pasty. Thus we meet in puddle pigs with mostly over 1–1·5 per cent. manganese, even up to 5 per cent. or more in those cases where puddle steel is the object in view.

In Bessemer pig manganese is liked. German Bessemer pig is especially rich in manganese, varying from 1–4 per cent. or more (Hoerde 5·3). Some Swedish works blow a pig rich in manganese and do away with final addition of spiegel, e. g. Westanfors, 5·1 per cent. manganese; Bangbro, 1·8. However, the manganese oxide which is formed eats the lining of the converter rapidly away. The English Bessemer process is started with about 1 per cent. manganese or less; many Swedish works convert pig with only 0·5–1 (Langhyttan 0·6), and so do American works.

In the basic Bessemer process a manganiferous pig is liked: Rheinisch Stahlwerk, 1·3 per cent.; Peine, 2·2; Witkowitz, 1·2; Le Creuzot, 1·5–2; Luxemburg, 1·5; Middlesborough, 1; Hoerde, 2·2, &c.; however, Ruhrort, Teplitz, and Kladno converting pig with about 0·4 per cent. shows that manganese is not a *conditio sine qua non* in the basic process. For the basic open hearth process, however, a certain amount of manganese is highly desirable to keep the bath fluid; 2·5 per cent. seems to be the highest record.

Manganese in Cast Iron.

Manganese tends to keep the carbon in the combined state, hence it causes a casting to be white unless its influence is outweighed by silicon. Large castings remaining longer fluid bear more manganese than small ones.

The influence on manganese proper of cast iron is not much studied, most of the results of experiments being caused by the influence of manganese on the state of the carbon. Thus manganese causes carbon to be as *a* carbon, it increases crushing strength, hardness, fluidity—in a word all that has been said for *a* carbon relative to its influence on cast iron may be repeated here because increase in manganese means increase in *a* carbon.

Obviously soft cast iron does not contain much manganese, e. g. Woolwich cast iron for guns, 0·5; Finspong ditto, 0·2–0·3; hot-blast pipes, 0·5.

Chilled castings, on the other hand, advantageously contain about 1 per cent., this being the case for rolls, railway wheels, &c. Very hard objects such as armour plates, Palliser shot, &c., may have even about 2 per cent.

Manganese in Wrought Iron.

The amount of manganese in wrought iron is so very little that its influence on this metal may be wholly neglected. Some analyses give 0·1–0·2 per cent., but manganese being of no importance or at all events seeming to be so, no information is to be had, analyses of wrought iron being scarce for one thing, and of manganese in the same scarcer still for another.

Manganese in Steel.

Of the greatest importance, however, is the presence of manganese in steel, and for clearness' sake we shall divide this topic into three parts, first manganese in ordinary steel, secondly the influence of manganese on the other elements in steel, and thirdly the special Hadfield manganese steel.

The discovery of Mr. Hadfield as regards the influence of a high percentage of manganese in steel is as bold as remarkable and useful, and fully deserves a special notice.

I.—Speaking in general this influence of manganese may be said to be very much like that of carbon, only in a smaller degree, and by a suitable

combination of manganese and carbon the most gratifying results may be obtained.

The effect of 1 per cent. manganese on the tensile strength is nearly equal to 0·2 per cent. carbon, thus being about one-fifth of it. When the carbon is kept constant and the percentages of manganese set out as abscissæ and the corresponding breaking loads as ordinates, the union of the corresponding points is nearly a straight line, the maximum being at about 3 per cent. manganese. On annealed steel manganese may be considered to be about equal to one-third carbon, thus each 0·1 per cent. manganese more or less will cause a rise or fall in the ultimate strength of 1·8–2 kg. per sq. mm.

More rapidly than the ultimate strength is the elastic limit raised by increasing the manganese, thus manganese when in larger quantities (more than 1 per cent.) causes brittleness. The elastic limit lies at 50 to 55 per cent. of the ultimate strength when not exceeding 0·6 per cent. manganese.

As regards ductility, the influence of manganese is only one-seventh to one-eighth of carbon; thus, of two steels having the same ultimate strength, the manganese steel will have larger elongation than the carbon steel, provided the manganese is not more than about 0·6 or 0·8 per cent. Whilst 0·1 per cent. carbon more causes a loss in elongation of about 4 per cent., 0·1 per cent. manganese more causes a loss of about 0·5 per cent. only, hence it may be advantageously used in structural steel where both strength and ductility are required.

It is easier to obtain certain strength and elongation figures when replacing part of the carbon by manganese than by exclusively using carbon, the severer the reception test the easier fulfilled when using manganese, but the limit is soon reached because of the rise of the elastic limit.

Crushing strength is rather increased also by manganese, so that transverse strength is higher too.

Rigidity increases with the manganese, or manganese bars when tested for transverse strength give a smaller deflection, the same being the case for a bridge girder made of manganese steel (we call a steel manganese steel when its content of manganese exceeds 0·2 per cent.). Resistance to torsion and to impact is also said to increase with manganese. The beneficial character of manganese shows best in annealed steel, but it becomes also more and more appreciated in other steel. It causes steel to be less sensitive to cold, of which property use is made in the case of rails in cold countries. It increases hardness to an extent about one-fifth of carbon.

As to the working properties, manganese seems to increase forgeability, however slightly. By the Pittsburg Bessemer Steel Co. it was found that a steel with 1·1–0·9 per cent. manganese rolled very well, 0·7–0·6 medium; 0·6–0·5 badly; 0·4 per cent. very badly. We rather think these results not due to manganese only, because the number of rails with 0·4 per cent. manganese is great and nobody has complained of their rolling badly.

Weldability is lessened by manganese because of

its easy oxidisability; manganese steel does not hold so well in the fire and is liable to burn.

Manganese causes more corrosion, as might be expected, it being more electro-positive than iron.

Manganese raises the melting-point, but when once molten the metal is more fluid than when no manganese is present. Although neither manganese nor any other element (except perhaps osmium-iridium) can replace carbon for its property of giving a steel hardenability (so to call it), yet manganese steel takes a harder temper than another steel of the same carbon point without manganese—of course under the same conditions of temperature, quenching bath, &c. The magnetism is greatly affected, the magnetic resistance increasing with manganese.

Manganese being of nearly the same density as iron does not alter the specific gravity of steel.

II.—Thus far concerning the direct influence of manganese, but it having a remarkable effect on some other elements and their influences, a few words must be said thereupon.

Manganese and Carbon.—Manganese keeps carbon in the combined state and very likely in steel as hardening carbon; as before said, it does not itself give the property of hardenability, but increases this property of carbon. Bright red-hot steel nearly free from carbon but containing 2 or 3 per cent. manganese, when quenched in cold water does not show, the least increase in hardness. A certain amount of carbon is implied in the property of taking temper, and the fact that carbon only is capable of causing a

hardened state seems to contradict the view that it was the iron itself that changed from an α iron into a β iron.

There exists a carbide of manganese of the formula Mn_3C similar to the Fe_3C, but as manganese metal made by reduction with carbon does not invariably contain much carbon it seems that manganese raises the saturation point of iron for carbon, as we have seen that rich ferromanganese may contain 7·3 per cent. carbon whilst for pure iron 4·5 per cent. carbon is the maximum amount that can be alloyed with it.

Manganese and Phosphorus.—Of much importance is the beneficial influence which manganese has on phosphoric steel, though entirely indirect. Manganese, as such, does not seem to alter coldshortness caused by phosphorus; but carbon has a very marked effect in this respect, the higher the carbon the sooner a certain percentage of phosphorus will cause coldshortness; so, for instance, 0·03 per cent. phosphorus is too much in very hard steel, whilst 0·1 per cent. does no harm in very mild steel.

Now manganese having no influence on the phosphorus coldshortness may advantageously replace part of the carbon, thus lessening the effect of the phosphorus but not lessening the strength of the steel. Exhaustive series of experiments have been made at the Terre Noire works regarding phosphoric steel and its amelioration by manganese. When, for example, a steel bath rather high in phosphorus, say over 0·1 per cent., is at hand, it would give but a very

poor material when a tolerably hard class was wanted. In this case however the remedy is to keep the carbon very low, say 0·2 per cent., and to give strength and hardness by 0·7–0·8 per cent. manganese, and an amount of even 0·4 per cent. phosphorus may be present and the steel still give an excellent rail of an ultimate strength of 55–60 kg. and an elongation of 25–26 per cent. (Terre Noire phosphoric rails).

Manganese and Sulphur.—The influence manganese has on the properties caused by sulphur is a most agreeable one. Sulphur causes redshortness, and this influence of sulphur is greatly diminished or neutralised by manganese, thus the more manganese in the steel the more sulphur it can stand without being redshort; or when a steel is redshort on account of sulphur, addition of manganese will remedy it.

This effect of manganese is very intense; whilst weld iron or steel (those kinds of iron and steel not obtained in a fluid but in a pasty state) is redshort with 0·02 per cent. sulphur and useless by 0·04 per cent. sulphur, steel (in the general sense, i.e. malleable iron obtained in the fluid state) may contain 0·1 per cent. sulphur without showing redshortness. This great difference is very probably due to the fact that bar-iron or steel is nearly free from manganese whilst steel almost invariably contains more or less of it. Besides this, manganese possesses the laudable property of assisting sulphur in scorifying, the result being that manganiferous pig seldom contains much sulphur. There are, or have been, desulphurising processes based upon the use of manganese as purifier.

Manganese and Silicon.—Manganese and silicon are rather opponents; manganese generally undoes what silicon has done, manganese being the stronger of the two, hence the resulting effect depends on their ratio.

Whether manganese has any influence on the form the silicon takes in iron (Fe) is not at present known, it remaining to be settled yet whether silicon occurs in two different allotropic states in iron (Fe) or not.* Manganese seems to lower the limit of saturation of iron (Fe) for silicon, at all events higher records are known of alloys of iron and silicon alone than of iron, manganese, and silicon. Very probably manganese has many influences still on other elements which occur or may occur in steel, but not much is known thereupon, hence we pass on to the third division of the subject of manganese.

III.—Under the name of manganese steel † Mr. Hadfield has introduced to us a metal of a wonderful character. The novelty is such as no other alloy can boast of because its most startling property is the

* Interesting are the facts that, on solidification, molten aluminium gives graphitic silicon (in plates like kish in cast iron), and molten zinc gives diamond-like silicon (in needles). These two and the amorphous silicon all show a different character, but in iron or steel no different forms of silicon have been separated yet.

† Some people object to the name steel, given to a body differing in so many respects from what they are accustomed to call steel. We fail to see any reason for this; when any malleable iron obtained in a fluid state is called steel, there is no need to trouble whether the carbon is low or high or whatever may be alloyed with iron (Fe), or whether the metal in question becomes hardened when quenched in water, or anything like that.

combining hardness and strength with great toughness when quenched in cold water.

As said under I., steel with more than 1 per cent. manganese loses in quality, the more the manganese percentage is raised; above 2·5 per cent. manganese and below 7·5 it is no good at all in the cast state, being extremely brittle and weak. In the forged state it may advantageously be used for cutting tools; when containing 7 per cent. manganese and only 0·4 per cent. carbon it is extremely hard. For dressing the tool it has to be heated red-hot, then quenched in cold water; it is softer then and can be filed; reheating to a bright heat and slow cooling in air restore the original hardness.

Of far more importance are the steels containing more than 7·5 per cent. manganese, notably those containing about 10–14 per cent. manganese. When increasing the manganese above 7·5 per cent. there is a large gain in tensile strength; the crushing strength is low but the metal is tough. When reaching about 10–14 per cent. manganese the most remarkable qualities may be given to the metal by quenching. The higher the temperature of the steel and the colder the water, i. e. the intenser the cooling, the tougher will be the material. The combination of high tensile strength and great toughness is a most agreeable one, and were it not for one drawback the use of such Hadfield castings would be much greater. This drawback is its extreme hardness.

Although the hardness is decreased by the water-

toughening process, it still remains such that the machining of Hadfield castings is very difficult, no special tool stands it, and, as we know, grinding with emery wheels is limited to shape. However, if we think of the enormous variety of objects manufactured by the Grüson works of chilled cast iron that in hardness equals the Hadfield castings we may hope to see the latter come into use more and more.

Samples of 13–14 per cent. manganese steel gave an ultimate strength of 100–110 kg. with an elongation of 50–45 per cent.; these specimens had undergone the water-toughening process.

A peculiarity is the low elastic limit, and this in many cases is a valued property, it causing a large factor of safety, but it is rather a pity that it is so very low in the cast state, viz. about 8–10 kg. The forged and water-toughened 13–14 per cent. manganese steel yields at about 30–45 kg.*

Neither does manganese steel possess a high crushing strength, hence a comparatively low transverse strength. As noticed by Pourcel, when considering ordinary steel with 0·5–0·8 per cent. manganese, manganese increases the torsional resistance; in the new steel the same is the case. In the manganese steel we see the combination of a large extension and a large contraction which, as said before, means great homogeneity.

* It must be remarked that, according to Mr. Hadfield, the yielding point of different steels is much lower than commonly given. If measured with as little care as is generally taken the manganese steel very likely would show a higher elastic limit.

Not improbably the high figure for ultimate strength is due for the greater part to the absence of local yielding, hence a test piece under tensile stress does not show a more or less sudden diminution of section at the fractured point but a nearly equally divided reduction of diameter.

As to the working properties, they are said to be good. The forgeability, as we have called it, is increased. Even 20–22 per cent. manganese steel (containing 2 per cent. carbon) is forgeable.

Overheated ingots crack under the hammer, but if heated to the right degree the only difference is that the manganese steel works hard, like hard tool steel. During the casting of the metal favourable and unfavourable properties are developed. The manganese steel is not so liable to honeycomb, and may be cast without the use of silicon. It is very fluid and may be run into thin plates. It cools rapidly and being hotter there is more contraction, hence more piping and setting; but these difficulties can be obviated by the proper use of big heads, the cutting off of which advantageously may be facilitated by putting asbestos rings between casting and head.

A very interesting and possibly highly valuable property is its non-magnetism. The magnetic and electrical resistance is very high and the permanent magnetism nearly nil.

Uses and Occurrence.

The use of manganese alloys has become an integral part of steel manufacture. The Bessemer process would never have been what it is were it not that the manufacture of spiegel-iron and ferro-manganese has been improved so much that those products can be obtained for a fair price. An English Bessemer blow in its original form did not start with a pig containing more than about 1 per cent. manganese, and an initial temperature not much over 1300° C.

It may be described as follows:—First period, burning of silicon, manganese and carbon nearly unattacked. Second period: the burning of silicon has produced such a heat (1 per cent. silicon burning gives a rise in temperature of 300° C., thus about 2 per cent. silicon which might be present would give about 600° C.) that the oxygen of the blast now throws itself upon carbon and manganese as well. In the third period carbon is still burning but much more slowly, the greater part being removed already: much iron burns as well now, and the more the longer the blow is kept up.

The presence of iron oxides causes redshortness and makes the metal unfit for direct use. To take away redshortness manganese in the form of spiegel-iron is used; the manganese combines with the oxygen of the iron oxides and is scorified; the carbon of the spiegel-iron will take part in the reducing of the iron oxides dissolved in the bath. Involuntarily

the bath receives carbon again in this way; therefore, when a very soft metal is wished, the use of ferromanganese must be resorted to.

Estimated according to percentage of manganese the carbon is much less in rich ferromanganese than in spiegel; thus the same amount of manganese can be used for reducing without consequently increasing the carbon of the steel too much.

The so-called German process is somewhat different from the one described. The initial temperature is a little higher, 1400° C. or more. Now in the first period carbon burns together with the silicon, and also manganese, which is present from 1–3 per cent. Although the end-product is richer in silicon and manganese, an addition of spiegel or ferromanganese is generally made.

A third modification is the Swedish process: the pig contains still less silicon (0·8–1 per cent.) and manganese (0·6–1 per cent.), the initial temperature higher or lower according to these figures and the end-product wanted. Now the blow is stopped when the silicon has disappeared, thus leaving much carbon in the metal, and this being the case not much iron has been burnt and a final addition of spiegel does not take place. The end-product is generally fairly hard, tolerably free from silicon and manganese, well suited for Sweden, where the pig is nearly free from phosphorus and sulphur and thus the product not requiring manganese.

It is this pure Swedish Bessemer steel that, relatively rich in carbon and poor in silicon, man-

ganese, phosphorus, and sulphur, is so well adapted to practise fraud with and to be sold as "crucible steel" either with or without being remelted. According to my views this fraud is quite allowable so long as consumers attach themselves to names. It is their business to know that they get a good metal, fulfilling their requirements; it is the steel-maker's to manufacture it, never mind how!

The above given sketches of the processes are only rough ones; it is evident that Bessemer blows are regulated according to circumstances and, fortunately, wide limits are given. In the basic Bessemer process, wherein the blow is continued much longer by the after blow, a spiegel or ferromanganese addition after tapping off the slag is necessary. In this case where, because of the prolonged blow, the product is a very pure one, low in carbon, silicon, manganese, phosphorus, rich ferromanganese is of special value; with its use a steel of a very mild character can be obtained, and although inevitably some manganese will pass into the metal, it may easily be kept under 0·5–0·4 per cent.

In the open hearth process the use of ferromanganese or, by preference, ferromanganese silicid, is often practised though not always necessary. For steel without blow-holes its use is highly advocated, though it is said also that it is quite possible to do without it. The process in this latter case very much resembles the crucible process, that is, the manganese of the bath reduces silicon from the lining, thus fulfilling the conditions for steel without blow-holes.

Similar to the killing in the crucible, the bath is kept quiet under a neutral slag and a reducing or neutral flame for about 20–30 minutes, then it may be tapped and, under certain conditions, will give steel without blow-holes.

After what has been said above it will be clear that nearly all steel contains more or less manganese and the use of it in the steel is widely adopted since it is recognised how good an influence it has.

Let us go over the list, as we did in the former chapter.

It is a remarkable fact that in most gun steels the amount of manganese is but little. In five samples from Krupp guns the manganese averages 0·14 per cent.; Firth, Whitworth, Cammell, Vickers gun steel averaged 0·23 per cent.; Terre Noire forged steel, 0·2; Trubia gun steel, 0·35; Witten 0·41; Bofors steel without blow-holes, 0·35-0·60; Terre Noire steel without blow-holes, 0·53–0·67. Barrels for rifles from different makers run from 0·01–0·72 per cent. (see complete analysis at the end of this work).

Knowing the beneficial effect of manganese on the elasticity of steel and its not imparting brittleness, it is rather striking that gunmakers seem to be afraid of manganese.* The splendid results obtained with Bofors guns containing 0·35–0·60 per cent. manganese indicate the needlessness of such a fear. It is

* Mr. Hunt's objection to manganese, that it gives a long chip before the drilling tool, seems rather a funny one. That manganese gives rise to water-cracks is completely contradicted by Hadfield's experiments.

just for a gun, which has to be highly elastic but may not get this property from much carbon, as it would then be unsafe owing to loss of ductility, that the use of manganese in the place of a higher carbon point suggests itself at once, because, as already said, manganese raises the elastic limit without diminishing ductility so much as carbon does. Mild steel, such as is used in structural work, often contains 0·3–0·4 per cent. manganese (Cocquerill's plates), or 0·7 (Forth Bridge), often only 0·15–0·25 (Motala boiler plate, and Obouchoff ship plate and angle-steel, Kladno bridge steel).

In accordance with what was said above about the Swedish Bessemer blow, it may be mentioned that Motala, Yggesund, Hiddekolm Bessemer mild steels contain from 0·05–0·25 per cent. manganese.

Steel wire for haulage ropes is generally low in manganese, 0·15–0·3 per cent., though Fowler's special wire of a very high tenacity (242·5 kg.) contained 0·59. Very hard wire may contain 0·2 per cent. or more, and as Hadfield's steel can be drawn into wire it seems that manganese does not interfere with the facility of being drawn out.

Rails may be divided into real manganese rails, or otherwise. Under the second heading we will take all those containing less than 0·5 per cent. manganese such as most German rails. French rails generally are high in manganese, e.g. 0·7–0·8 per cent. (Terre Noire); others, as the North-Eastern hematite rails, 1·18; Edgar Thomson rails run from 0·77–0·98 in fifteen examples.

As already mentioned, manganese rails are specially adapted for use in cold countries, where rails rendered hard by carbon will snap, and rails made hard and strong by manganese will hold (Hadfield also observes that his steel is non-sensitive to extreme cold). The severe Russian tests are passed by manganese rails, and practice in Finland has shown a real superiority of highly manganiferous rails, viz. 0·75–1·4 per cent. manganese. After a 3½ years' use only one in 38,000 was broken. They withstand a drop test of 1 ton from 3 metres height in 1 metre between supports.

A still larger amount of manganese is advocated by some for the use of tires; Arnold's normal tire contains 1·25 per cent. Russian forged tires are not so high in manganese, but a tire from Bochum showed 0·98. Knowing its resistance to repeated shocks, the presence of manganese in rails and tires is not surprising; the only thing is, that it always makes the product higher in price, which in the case of rails is an important item.

All steel castings free from blow-holes contain something like 0·6–0·8 per cent. manganese for well-known reasons. The pretended increase of torsional resistance suggests the use of manganiferous steel for shafts (Krupp shafting steel 0·6 per cent. manganese), as also for crank-axles and railway carriage axles.

Noticeable is the low manganese in the hardest class of steel such as tool steel; from Holtzer e.g. all kinds having only 0·05 per cent.; die steel (Royal Mint), 0·1–0·45. Springs, however, sometimes con-

tain 0·8 per cent. (St. Etienne), but Terre Noire only puts 0·3 per cent. into them; also for watch-springs. The reason for this is probably that for these steels hardness is the principal thing and ductility not much demanded.

No definite figures being known to me as to the amount of manganese in projectiles and armour plates I can only say that I do not see any reason why it should do any harm; on the contrary, the character of manganese steel indicates its fitness for these purposes.

As to the use of Hadfield's special manganese steel, not much information is to hand yet from practice, but that gentleman's experimental researches indicate a great future for it. In fact Hadfield steel possesses so many striking properties that its use for first class steel objects * will certainly become established in the future.

A few suggestions may not be out of place. The extraordinarily high ductility makes it specially adapted for all things where a high factor of safety is employed: haulage ropes, for instance, subjected to constant wear and tear. The difficulty of drilling holes, planing, &c., precludes its use in bridge work and the like, besides it would not allow of a sufficiently high strain, and the usual factor of safety of 3·5 or 4 has proved to be quite enough. Its higher price excludes it for rails, but its hardness and non-brittleness make it specially adapted for tires. For

* Its higher price will exclude it for second class things such as rails and a good many more.

a tire hardness is essential, but the risk of a fracture is too dangerous to allow of its being obtained by carbon only. Other railway material may advantageously be made of Hadfield steel, as proved by the coupler manufactured by Mr. Hadfield.

Numerous machine parts may be made of Hadfield steel, such as cross-heads, slide-bars, and all those exposed to wear. The metal seems well appropriate for bearings, being antifrictional. For anvils, steam-hammer heads, and rolls, for all kinds of crushing machines—in a word, for all articles requiring extreme hardness, Hadfield steel bids fair to be a dangerous rival of chilled iron; were it not that its higher price puts a limit to its use.

For ordnance material there are only two applications, armour and projectiles. As a gun-metal it is at once excluded by its low elastic limit. A strain of 15 kg. is the least a gun may advantageously be constructed upon,* which means that the elastic limit shall be at least 30 kg. Hardness of bore would be very welcome, but the hardness of Hadfield steel is too much of a good thing and makes machining too costly and too lengthy. For gun construction, thus, Hadfield steel is not appropriate at all, neither is it for gun carriages, for too well-known reasons.

It would not do either for shell with bursting charge, on account of its great toughness, nor for

* It becoming more and more usual to express the efficiency of a gun in energy per ton of gun, it is evident that it is unadvisable to go below the generally employed strain of 15 kg. per sq. mm.

solid shot because of its low resistance to crushing forces; but extremely well for shrapnel, in which toughness of case is greatly desired, and they may easily be pressed out of a plate and do not require much tooling.

The most interesting application of its hardness and toughness would be the use for armour plates for coast defence. Chilled iron is at present the only metal that stands a few but very heavy blows, such as may be expected in coast defence, and Hadfield steel possessing in a still higher degree the excellent qualities of chilled iron, we may expect much of it. No doubt its proper use is for dome-shaped turrets of the Schumann type, the segments not requiring any machining beyond a little grinding of the sides. The ideal armour is either one locally yielding like wrought iron or mild steel, or one not yielding at all, like chilled iron; the first very good in case of prolonged attack by comparatively light artillery, the second in case of defence against very heavy guns. A metal being extremely hard and extraordinarily tough combines these two advantages of both kinds of armour and has a fine future, so much the more as its price, whatever it may be, is no objection provided it is the best material.

It is doubtful whether Hadfield steel will come into use as a tool steel, first class carbon steel being excellent already. A good use is to be made of its non-magnetism for bed-plates and frames of dynamo machines, also as wire on resistance boards for its high electrical resistance.

SILICON (Si).

Metallurgical Behaviour.

Up to the present time silicon has never been reduced from its oxide SiO_2 by carbon only. The presence of another metal, however, with which the silicon can unite, greatly facilitates the reduction, and the preparation of silicon alloys with different metals and metalloids offers no difficulty.

The quantity of silicon reduced in a blast-furnace depends on the nature of the flux and on the temperature. The higher the SiO_2 in the cinder, the more opportunity for reducing, but even from very basic cinders part of the SiO_2 gets reduced. The higher the temperature the more silicon will pass into the iron, hence it is that Swedish charcoal furnaces seldom employ a very hot blast so as not to get a rich pig. The ancient iron pipe stoves give a sufficient heat for the smelter who does not want any more heat, as in most cases a white forge pig is wanted to be treated in the Lancashire low hearth.

The flux in a charcoal furnace generally being high in SiO_2 for other reasons, there is a reason the more not to heat the blast too much.

It is evident that when foundry pig is wanted instead of forge pig the conditions are altered and a hot blast will prove very useful, seeing that the temperature in a charcoal furnace is naturally lower than in a coke furnace. Sometimes the cinder in this latter case contains 60–70 per cent. SiO_2.

The manufacture of ferrosilicon, that is a pig iron with about 10 per cent. silicon, is coming into use; however the reduction of silicon is not effected for nothing, much fuel must be sacrificed, as will be readily understood. For very rich silicon alloys 2500–3000 kg. coke are consumed per ton of pig. It has been mentioned already that manganese greatly facilitates the reduction of silicon, hence it is that for silico-spiegel a little less than 2500 kg. suffices.

In oxidising processes silicon behaves quite differently from the metalloid in the free state. Free silicon exists in three allotropic modifications, one amorphous and two crystalline. Crystalline silicon may be like graphite in plates or in needles, so called diamond silicon. Heated without free access of air the amorphous silicon changes into crystalline and heat is developed; heated otherwise it readily burns till it becomes coated by SiO_2 which prevents further oxidising. The crystalline silicon does not burn at all, not even at a white heat in pure oxygen, but strangely enough rapidly burns at a cherry heat in CO_2. Though distinctly visible as graphitic silicon in molten aluminium and as diamond-like silicon in molten zinc, the question whether silicon in iron assumes different states is disputed.

Silicon always behaves in the same way and is always separated in the same state, nevertheless there remains much probability for more than one state. One fact is that the silicon present in iron is remarkably eager to burn whenever there is a

chance to do so. Remelted in cupolas or reverberatory furnaces the pig has generally lost silicon, which loss however is greatly dependent on the amount of manganese present, and eventually the percentage of silicon can be raised on account of the manganese having reduced silicon from cinder or furnace lining.

In most cases, however, silicon will decrease every time it is remelted, and it is a fact well known to iron-founders that pig or cast iron often remelted will at last give white castings.

For the low hearth silicon is considered a nasty thing: it consumes fuel and prolongs the duration of the process; hence Swedish forge pig is run into iron moulds so as even to avoid adherence of sand to the pigs. In puddling furnaces silicon is not wanted either and should never exceed 1 per cent. in the pig.

The old fining processes are pretty well abandoned for the very good reason that, in the first place, fining—that is, in the limited sense of the word, burning off silicon—costs money in itself; and secondly, because pig low in silicon is made more cheaply than that high in silicon.

The silicon disappears pretty quickly in low hearth and puddling furnace, because of the presence of a cinder very rich in iron oxides. In the acid Bessemer process, on the other hand, silicon is the very thing wanted; herein silicon is the heat producer proper and without it the process would ıail invariably as the metal would get colder and

colder and the heat required to keep the bath molten increases rapidly as the carbon decreases.

For comparison the following figures may be given:—

1 p. c.	silicon	that burns	causes a rise in	temp. of about	300° C.
„	manganese	„	„	„	69° C.
„	iron	„	„	„	44° C.
„	carbon	„	„	„	6° C.

From this table it is obvious that none can compete with silicon.

Though the original Bessemer blow required a pig with 2 per cent. silicon, less may be used when the initial temperature is high enough, viz. about 1500° C.; the charge is overheated then, and above 1400° C. the affinity of oxygen for silicon and carbon being about equal, the process can be finished in the way detailed in a former chapter. Whether it is more advantage to use a pig with 2 per cent. silicon or one with 1 per cent. and to overheat this, depends upon local circumstances.

In the basic Bessemer process silicon is the blackguard, a fact not acknowledged for long after the introduction of the process. Here phosphorus must play the role of silicon, which it willingly does, each per cent. giving a rise in temperature of 183° C. It was Prof. v. Ehrenwerth that scientifically pointed out the necessity of a large percentage of phosphorus and the absurdity of much silicon in Thomas pig. 1 per cent. silicon being as a heat-producer equal to about 1·6 per cent. phosphorus, it is easy to get to know how much phosphorus must

be present in a basic pig of known silicon point. Silicon prevents the separation of phosphorus, hence the lower the silicon the better; besides, all silicon has to be neutralised by the lime, and as lime is added for the phosphorus and not for silicon, all that goes to the SiO_2 may be considered as wasted.

In the open hearth process the amount of silicon does not matter very much, but the more there is present the more quickly the charge can be finished, its heating power being known.

The Martin bath, however, being generally made up for a great deal of scrap, is seldom rich in silicon.

As we have said, silicon plays no actual part in the crucible process, but it becomes reduced from the pot and passes into the steel. It is a remarkable fact that new crucibles only give noticeable quantities of silicon, and it being known that Krupp never uses his crucibles twice—as is said, on account of the risk of cracking of old ones and the damage thus caused being greater than the advantage of economy—we feel rather inclined to believe that the true reason why at the Krupp works the crucibles are used once only is that it has been observed that a better killed steel is obtained, and though not knowing (or perhaps knowing) the real cause, people went on using new crucibles only. Fortunately, the old idea that steel melted in a crucible, thus protected against injury of fuel (of solid fuel, not against gaseous fuel), would not alter its composition, is done away with, thanks to the investigations on this point by Mr. Brand,

Mr. Müller, and others, and with it the preference for crucible steel ought to be given up as well.

In what respect does crucible steel differ from good open hearth steel of the same composition, same conditions of heat, cast, &c.? Most certainly no steel-founder can in earnest pretend an ingot cast from a thousand or more pots to be more homogeneous than one cast from one molten mass of one temperature, one composition, one character. May be the charges for the crucibles are carefully selected and eye-tested and weighed off, but we do not believe in the possibility of having some thousand or even 1800—as said by the Krupp people of the ingot for the A-tube of a 100-ton gun (70 tons)—of equal chemical composition, equal heat, equal exposure to heating gases, &c., in say at least ninety different furnaces. Think of how much time it would take to empty 1800 crucibles! what a splendid opportunity to liquation is thus given! But a more detailed consideration would be too much out of place here; we may remark, however, that the Krupp gun steel being of a very high quality, there is no need for consumers to know how it is made.

Influence of Silicon on Pig Iron.

Silicon has a most marked influence on the total amount of carbon, this latter falling with increase in silicon, and the intensity is such that it quite outbalances manganese in this respect; thus when adding 4 per cent. silicon to ferromanganese of 50

per cent. manganese containing about 6 per cent. carbon, the carbon will fall to something like 2·5 per cent. Ordinary ferrosilicon contains about 10 per cent. silicon and 1·5 to 2·5 per cent. carbon (French ferrosilicon, Mont Real ditto, Middlesborough, &c.). But seldom does the carbon reach 3·5 per cent. as in case of the ferrosilicon of the Société des Aciéries de France (9 per cent. silicon, 3·5 carbon, 1·75 manganese), or as high as in the sample from St. Louis, Marseille (12·6 per cent. silicon, 4·2 carbon, 2·5 manganese). When raising the amount of silicon to 20 per cent., 1·5 per cent. carbon is the maximum, generally it remains under 0·75. The highest records of silicon contents are those made by Riley, 23 per cent., manufactured in plumbago crucibles, and Hahn's with 30·5.

In the blast furnace 20 per cent. seems to be the utmost. It is rather a good thing that the amount of carbon counteracts that of silicon, because a high temperature in the blast furnace tends to produce a rich pig, but at the same time causes a pig rich in silicon, and more silicon meaning less carbon taken up, we see these two causes working against one another. Of course the basicity of the slag will have much influence on the silicon point of the pig. Thus for instance in Swedish charcoal furnaces, where the fuel does not admit of a very high temperature nor is the blast heated much, the commonly acid slag (60–70 per cent. SiO_2) does no harm, though the forge pig must be low in silicon. On the other hand, it follows also that charcoal furnaces

are not adapted either for ferromanganese or ferro-silicon manufacture.

The next important property of silicon is that it causes the carbon to take the graphitic form; however, this property attains a maximum value at about 4 per cent. silicon. It is to Turner that we are indebted for much information about silicon, and he pointed out this property which of late has been fully confirmed by Hadfield's experiments. Turner showed how by increase of silicon above about 4 per cent. the *a* carbon increases as well.

3·9	per cent.	silicon	with	0·20	per cent. *a* carbon;
4·7	„	„		0·37	„
7·3	„	„		0·38	„
9·8	„	„		0·69	„

and Hadfield's ferrosilicons contained

8·8	p. c.	silicon,	0·05	p. c. *a* carbon,	2·35 p. c. *β* carbon;
11·2	„	„	0·06	„	1·85 „
14·0	„	„	0·23	„	1·20 „
17·8	„	„	0·11	„	0·55 „

This is the more striking as the total carbon decreases rapidly, thus giving relatively an increase in *a* carbon. It may be well to show the *a* carbon in percentages of the total carbon: thus we get respectively 2·1, 3·2, 16·1–16·7 per cent. of the total carbon as *a* carbon.

As in the samples the manganese decreased as well from 2·4–1·1, it tells still more for this peculiar behaviour of a high amount of silicon. The influence

of silicon on the fluidity of pig iron seems to be in favour of it, as brands rich in silicon are well known for their imparting fluidity.

Hadfield does not believe this is due to silicon itself, but to its influence on the carbon, viz. its increasing the β carbon. However, as *fluid* iron does not contain β carbon, but has all its carbon in the combined state, his explanation is not satisfactory.

Knowing the great difference in specific gravity of iron and graphite (7·5–2·3: thus, taking iron as unit, β carbon becomes only about 0·3), and knowing how when solidified the graphite is equally diffused throughout the whole mass, it is evident that when fluid iron did contain β carbon it would at once come to the surface.

This phenomenon may be actually observed when the iron is over-saturated with carbon, in which case formation of kish takes place, that is, a separation of β carbon, and this formation of kish is often caused by silicon. Given an iron saturated with carbon, now add silicon, which, as we have said, lowers the saturation point, then that iron will be over-saturated and separation of carbon, either as kish or, under some circumstances, crystallised, will take place.

These considerations would lead one to think that it is certainly the silicon that imparts more fluidity, so much the more as silicon raises the melting-point of the pig, which also may be due to silicon itself or to its diminishing the carbon. The fact that carbon lowers the melting-point and silicon lowers carbon, is one reason, but a still more prominent one

is that it is α carbon, not β carbon, that influences the melting-point. (β carbon being only mechanically mixed cannot have any influence on the melting-point; though by separating iron molecules it makes the mass less dense or compact and thus facilitates melting; but this is obviously another thing.) Silicon increasing the β carbon and decreasing total carbon, thus in a double way decreases α carbon, so it can be only the silicon itself that imparts fluidity. Practically it is proved by the fact that a puddler does not like grey pig to convert, because, first it takes more time and fuel to melt it, and then it melts suddenly and becomes too thin. (At the moment the β carbon changes into α carbon, which happens at a very bright heat, the iron at once melts.)

Whether silicon facilitates or not the expulsion of sulphur from the pig remains an open question as yet. Turner thinks this to be the case, and quotes analyses, but Prof. Ledebur, one of the most eminent German metallurgists, explains the often observed fact that the higher the silicon the lower the sulphur is in the pig, by saying that the higher amount of silicon indicates a higher temperature at origin; and all authorities, Mr. Turner included, agree on the point that a higher temperature is unfavourable for sulphur to be taken up.

Considering only the chemical character of the silicon and sulphur, one would expect both to increase simultaneously (a high amount of silicon meaning an acid slag and a basic slag being wanted

for sulphur expulsion); however, analyses show the reverse:—

	Silicon per cent.		Sulphur per cent.
Seend Wiltshire No. 1	4·7	..	0·04
„ „ „ 2	3·7	..	0·08
„ „ „ 3	3·2	..	0·1
„ „ „ 4	3·1	..	0·2
„ „ „ 5	2·3	..	0·16
„ „ „ 6	2·2	..	0·25
Hæmatite „ 1	2·6	..	0·05
„ „ 4	2·2	..	0·12
„ white	0·3	..	0·54

These and others show that decrease in silicon gives increase in sulphur, which however does not at all prove that silicon expels sulphur. No. 1 pig is made at a much higher temperature than No. 6.

Prof. Ledebur has proposed to classify pigs according to their silicon contents, which would be a very rational thing, and far better than the now followed rule to judge pigs by their fracture, the constituents of pig iron being so many that the fracture often tells very little indeed.

Influence of Silicon on Cast Iron.

Turner, who experimented in a logical way with silicon in cast iron, brought out some new things as to the mechanical properties. From him we learn how a maximum of crushing strength is obtained with about 1 per cent. silicon, being about 146 kg.; a maximum of tensile strength with about 2, being about 25 kg.; a maximum of transverse strength with about 1·4. Although these figures are obtained

when having to do with a cast iron of only 2 per cent. carbon, there is no objection whatever always to make such an iron of so low a carbon point. It has often been the practice to add steel scraps in the cupola to obtain a strong casting, and this practice obviously led to having an iron with a lower carbon point than is commonly present in cast iron.

When a cast iron of 25 kg. tensile strength can so easily be made instead of 10 or 12 kg. as is generally the case, why is it not done?

The value of Turner's experiments lies in his having worked under practical conditions of carbon and manganese. It need not be repeated here that the influence of silicon will chiefly be due to the ratio α carbon–β carbon it causes; but whether it is silicon direct or indirect, very good results may be obtained by a pretty high amount. Turner gives a list of the best silicon percentages in cast iron, which we shall reproduce, though, as he states himself, the figures are liable to modification according to circumstances.

Maximum	hardness obtained	with silicon under	0·8 p. c.
„	crushing strength	„ about	0·8 „
„	modulus of elasticity	„ „	1·0 „
„	density	„ „	1·0 „
„	transverse strength	„ „	1·4 „
„	tensile strength	„ „	1·8 „
„	softness and working qualities	„ „	2·5 „
Minimum of α carbon		„ under	5·0 „

Of late there have been made in Germany extensive and costly experiments as to the effect of different mixtures of cast iron and other irons; these experi-

ments, however, for want of logical connection and definite figures, do not give the least certainty, so much the less as, in the numerous meltings, not one but all the constituents vary so much. The question whether it is more advantageous to use ordinary or mixed pigs for the foundry, or to use the lower grades (white pig) and scrap with addition of ferrosilicon, depends solely upon local circumstances. At one time it was announced in Germany and France that there was no more need for the Scotch foundry pig, ferrosilicon could be used instead; but as the manufacture of ferrosilicon greatly increases in cost with increase in silicon, it was found to be in most cases more economical to go on using No. I. pig.

Jüngst tried a mixture of white pig and ferrosilicon for a casting of hydraulic cylinders, and obtained excellent results without doubt (the turning chip of a large diameter being 550 mm. in length); but might not he have got the same with another mixture that likewise contained 2·2 per cent. silicon, 0·5 α carbon, 2·2 β carbon, 0·5 manganese, 0·9 phosphorus, 0·1 sulphur?

Besides the highly beneficial effect a certain amount of silicon has on the strength of cast iron, a few words may be said of its other properties. The tendency to separate carbon as β carbon, and thus to produce soft and nice castings, has already been spoken of. The use of No. I. and II. pig, that is, pigs rich in carbon and silicon, is chiefly as addition when old iron is melted. Often remelted the iron loses more and more silicon, and will turn white, but

this may be prevented by the use of silicon in some form or another, viz. No. I. pig or ferrosilicon. Some pigs manufactured from certain ores enjoy a reputation for softness, and many ironmasters think that property to be a specialty of such pig; in reality silicon is the softening agent, hence any pig rich in silicon is a softener. Silicon in some larger amounts has one thing against it, that is its increasing contraction on solidification, thus causing more piping, the result of the higher temperature.

Influence of Silicon on Wrought Iron.

Seeing that in all processes of weld iron making silicon is kept away as much as possible, and that the temperature of their manufacture is invariably relatively low (compared to a Bessemer blow for example), it being thus clear that when a decarburisation has been performed this means that the greater part of silicon has been eliminated first, it is no wonder that the amount of silicon in wrought, i. e. weld, iron generally is low: Swedish Lancashire, 0·02 per cent.; Yorkshire puddled best, 0·06; Swedish puddled, 0·1: however, sometimes 0·25 is recorded in Yorkshire and Staffordshire puddled.

When the carbon is low, which of course is the case in wrought iron, the amount of silicon is absolutely harmless for the strength, but the weldability very likely will be diminished, silicon being quite fatal to welding (Hadfield). This is rather a pity, as here silicon and carbon go hand in hand;

thus the more carbon the product contains, such as steely iron or fine grained, the more silicon it has too, and the less weldable it is. Puddled steel has still more carbon and silicon, and thus is still less weldable. Mrasek found up to 1 per cent. silicon not to affect the welding property of iron or steel, but nearly everybody agrees in the welding being best the purer the iron.

Influence of Silicon on Steel.

Poor silicon has been scolded for a long time, but later investigations have shown this to be quite wrong and that silicon is not so bad after all. Silicon increases tensile strength, however, in a much less degree than carbon, being only about one-tenth of this, 0·1 per cent. silicon more giving a rise in the ultimate strength of 0·5–0·6 kg., whereas 0·1 per cent. carbon gives 5–6 kg. increase.

Experiments carried out by Prof. Austen and Turner on steels with about 0·17 per cent. carbon and 0·57 manganese and increasing in silicon from 0·01–0·5 per cent., are very instructive. They show how, under those conditions, the elastic limit rises very little, only from 33–40 kg.; the ultimate strength varying from 45–55 kg.; the decrease in elongation and contraction—i. e. the loss in ductility —being but slight; thus they conclude that 0·5 per cent. silicon in no way affects the ordinary properties of mild steel, provided manganese is present Hadfield, again, experimented upon rich silicon

steels in the same logical thorough way as he did on manganese steels, and found a maximum of strength at about 4 per cent. silicon. Such metal, however, having an ultimate strength of about 77 kg. and an elastic limit of 70 kg., but without either elongation or contraction, is of course practically of no use.

The case is different with steels containing up to 1·6 per cent. silicon; with these an ultimate strength of about 59 kg., and an elastic limit of about 48 kg., an elongation of 31 per cent. (on 25 mm.), and a contraction of 51 per cent. are met with. Although it is hardly to be expected such metal would purposely be made, there are special cases in which silicon would render valuable service. In a previous chapter it has been remarked that the coldshortness caused by phosphorus is the sooner felt the higher the carbon; now silicon does not affect that coldshortness, and thus supposing a steel bath unintentionally phosphoric, it can be saved, that is, a useful metal of a certain strength may be got from it, when the carbon is kept low, say under 0·2 per cent., and the desired strength given by silicon. In the chapter on manganese we have seen how manganese can fulfil the same duty; however, under certain circumstances silicon might be used with advantage.

Prof. Kennedy's determinations of the modulus of elasticity of Hadfield's silicon steels show a highest value at the lowest silicon amount. The fact that 2·7 per cent. silicon steel has been drawn to wire, clearly indicates that the loss in ductility is not

great. As to crushing strength, silicon seems to be unfavourable. Considering the working qualities, it may be said that silicon up to 6 per cent. does not destroy malleability provided the carbon is low. All experimenters agree herein, that they found silicon not to injure the forging. Hadfield found silicon not to cause redshortness before it was present in more than 6 per cent. Evidently the redshortness will be caused the sooner the higher the carbon, but it is strange that Turner found silicon to cause redshortness in Bessemer steel at a few hundredths of a per cent., and Turner's carbon *was* low. However, Hadfield's manganese is a few tenths of a per cent. higher, which might be the cause of the difference, although it is rather too little for that. Silicon does not affect coldshortness, which has been proved anew by various bending tests.

More puzzling is the question of welding. All samples of Prof. Austin and Turner containing about 0·17 per cent. carbon, 0·57 manganese, and varying from 0·01–0·5 per cent. silicon, welded perfectly. Mrasek also, who experimented with higher silicon contents, found that Bessemer steel with about 1 per cent. silicon, 0·5 carbon, 1 manganese, welded very well. On the other hand, Reiser, who has great practice in tool steels, states that a steel with 0·7 per cent. carbon and 0·4 silicon is unmanageable in the fire, welding being out of the question; and many think the presence of silicon in steel one of the reasons why steel is less weldable than iron, which, as has been said, is generally low in silicon. These

different statements, however, are not so contradictory as they may at first sight seem.

Prof. Ledebur pointed out that Mrasek's metal contained sodium (Mrasek used sodium in the production of his ferrosilicon); however, we doubt whether sodium, being one of the most easily oxidisable metals, would facilitate welding.

I may venture to give another explanation. Seeing, from other processes, that manganese protects silicon from oxidising, it will very likely do the same here, thus preventing the intermolecular placing of silica between the iron molecules; and it may either be that manganese oxide gets more easily expelled from the mass, or else that both oxidise and form an easily meltable thin slag. However this may be, we notice a decided difference in Mrasek's samples with and without manganese. Thus, for example, a sample containing about 1·4 per cent. silicon, 0·17 carbon no manganese, was unweldable; one containing about 1·3 silicon, 0·21 carbon, 0·36 manganese, welded, although the higher carbon point of the latter is not in favour of welding. Another sample containing about 1 per cent. silicon, 0·28 carbon, no manganese, was unweldable; and one containing about 1 silicon, 0·47 carbon, 1 manganese, welded very well. Here the influence of the manganese is clearly visible and is such that the much greater amount of carbon is not felt. This then explains why Hadfield, whose steel contained only 0·14–0·3 per cent. manganese gave negative results as to welding.

That Prof. Austen and Turner's silicon steels,

containing 0·5 per cent. silicon and 0·18 per cent. carbon, welded perfectly, may also be explained by the fact that they contained 0·56 per cent. manganese. We saw how in Mrasek's experiments 0·36 per cent. manganese had a most marked influence on steel containing as much as 1·3 per cent. silicon.

We are not aware whether Reiser experimented with steels high or low in manganese, and so can say no more about his asserting silicon to be unfavourable to welding.

Dr. Müller published some very interesting results as to the influence of silicon on tool steels, and found that even 0·8 per cent. silicon in hard steel (0·8 per cent. carbon) has no injurious effect, and thinks 0·5–0·6 per cent. silicon rather an improvement for the quality. He tried different samples practically in the shop and obtained remarkable results as to the quality of his trial steels, viz. their keeping edge. The best results were obtained with 0·58 per cent. silicon, 0·19 carbon, 0·4 manganese. Special remarks on welding are not made by that gentleman.

As to rolling, earlier statements said 0·15 per cent. silicon to be a maximum, whereas in Prof. Austen and Turner's series, the highest, 0·5 per cent. silicon, rolled very well.

The natural hardness of steel is increased by silicon, which seems to be equal to ¼ carbon, i. e. 0·4 per cent. silicon more causes the same increase in hardness as 0·1 per cent. carbon, which property will prove useful in the above mentioned case where silicon was added to phosphoric steel.

The property of taking temper, which we shall call the hardenability, is not altered in the least by silicon —a fact proved anew by Hadfield's experiments. A rich sample containing 5·5 per cent. silicon (0·26 carbon) showed only a slight skin-hardening when quenched in cold water from a welding heat, and was quite as soft inside as before that operation. Hadfield draws attention to the fact that those rich silicon steels stand a very high heat exceedingly well, thus again showing that silicon itself does not cause redshortness. This is something new, as it was known before that silicon causes the steel to burn, and this burnt silicon, i.e. SiO_2, is very likely to have been the cause of the bad name silicon has had so long, what was due to SiO_2 having been attributed to silicon.

Turner pointed out how basic steel very low in manganese (about 0·1 per cent.), containing over 0·2 per cent. silicon, did not roll, whereas after addition of 0·5 per cent. manganese it rolled very well, even with 0·5 per cent. silicon. Thus the beneficial effect of manganese on silicon steels is once again manifested.

With regard to magnetic properties, it is known that silicon raises the limit of manganese for non-magnetism, that is, whereas spiegel-iron with about 25 per cent. manganese is non-magnetic, addition of silicon makes it magnetic again—a fact that causes trouble when the classification of spiegel-iron or ferromanganese is based upon the non-magnetism of the latter.

Hadfield's 4·4 per cent. silicon steel (0·18 per cent. carbon) proved to have less susceptibility and more retentiveness than good soft iron, and enormously less retentiveness than good magnet steel. As to rusting, silicon being more electro-negative than iron, retards rusting, like all other more electro-negative elements (except sulphur); moreover silicon greatly disturbs chemical action of acids.

Ferrosilicon is with difficulty soluble in acids;* sulphuric, hydrochloric, and nitric acids have little action.

The structure of cast silicious steel does not undergo any visible alteration either from annealing or cold water quenching.

Silicon diminishes the fluidity of steel (according to Hadfield) and the steel pipes a great deal more than ordinary steel, which will involve the use of big deadheads to fill up, and the shrinkage is considerable, thus increasing the difficulty of internal strains.

On the whole, then, the use of castings of rich silicon steel is not to be advocated, but it is of considerable value to know that an amount of 0·5 per cent. silicon does not interfere with the quality of the steel, since steel without blowholes generally contains about 0·4 per cent. silicon.

* The best solvent liquid for ferrosilicon is bromium dissolved in hydrochloric acid.

Uses of Silicon.

We distinguish two uses, one in the iron foundry and one in the steel foundry.

The use of silicon in the iron foundry is nearly as old as the founding itself, but the acknowledgment of silicon as one of the most, if not *the* most important element is of more recent date—at all events its general acknowledgment. However, it is remarkable that people come forward with new laws and new discoveries which after all have nothing new in them at all, and it is rather a pity when a man puts his skill in investigation, that he has not beforehand taken notice of what people before him have done. The amount of American metallurgical novelties and discoveries that are old news is amazing; more than ninety-nine per cent. of them are printed in the treatise on Iron Metallurgy of Prof. Ledebur. Germany's greatest and most lucid metallurgist. As the nature of pig iron essentially depends upon its contents of silicon, it is really a pity people do not follow Prof. Ledebur's proposal.

The silicon in pigs varies from 0·1–0·5 per cent. in white and basic iron, to about 5 or 6 per cent. in glazed iron, and about 10 per cent. in ferrosilicon. No. I. iron proper is rich in silicon, 2·5–3·5 per cent., and is used as a softener to other brands. For long a certain nature was attributed to a certain iron ore to give a certain brand. To some extent this is perfectly right, but then it should be borne in

mind that nature can be altered at will to any other nature by change in burden, blast, temperature, and pressure, and nowadays no iron needs to be considered useless (unless it contains a high amount of sulphur or other out-of-the-way elements). Glazed pig such as contains 5 or more per cent. silicon, stated as absolutely useless in the foundry, is nothing less than that. Obviously such iron is not to be used in the forge or the like; such special pigs have special uses: a mixture of glazed pig and white pig in convenient proportions will certainly give an iron which shall be of suitable composition, and hence may very well be made use of.

If the chemical composition of the pig is known its proper use will at once be known as well, but it is that execrable working by the rule-of-thumb that makes people believe such strange things as that a rich silicon iron is "absolutely useless." The facts brought out by Turner's experiments show that silicon is not only sought for as a softening agent, but should also be desired as a strengthening element in cast iron. This will increase the demand for siliconised pigs, but whether it will pay to smelt very rich ferrosilicon is doubtful.

Briefly, the use of silicon in the foundry is, in the first place, for its property of softening, i. e. converting α carbon into β carbon; in the second, to impart strength. Of course, in the special case of chilled iron casting, silicon is kept away.

In many cases it will be very agreeable to be able to make a good casting of old iron scrap, poor iron,

and even steel scrap mixed with glazed pig or ferro-silicon and remelted in the cupola.

To show the silicon in different grades, the following list of hæmatite pigs will be useful:—

	Glazed.	No. 1.	No. 2.	No. 3.	No. 4.	Mottled.	White.
Silicon per cent.	6·5	2·5	2·25	2·0	1·75	1·0	0·8

Though the silicon contents vary greatly we may in general say that grey pigs contain 2–3·5 per cent., mottled 1–2, white pig 0·1–1.

As before remarked, charcoal iron contains less silicon than coke iron, thus charcoal grey iron seldom runs above 1·5 per cent.

Cold-blast iron, too, is very low in silicon. Thus, Vordernberg cold-blast white iron has 0·1 per cent.; Schwechat ditto, 0·15; Betler ditto, 0·1; Clarence, 0·3.

Forge iron is low, as already said:—Cleveland, 0·6 per cent.; Dowlais, 1·2; Luxemburg, 0·4; Micheville, 0·4. Some analyses of basic pig will do to prove the low silicon figure:—Peine, 0·5 per cent.; Hoerde, 0·4; Witkowitz, 0·1; but Le Creusot, 1·2; Luxemburg, 0·75; Middlesborough, 1; Ilsede, 0·1; &c.

The use of silicon in the steel manufacture is greatly coming into favour. The use of silicon as a heating agent in the ordinary Bessemer blow has been mentioned; commonly Bessemer pig contains about 2 per cent. silicon, e. g. Hoerde, 2·6; Schwechat, 2·3; Hughes, 1·8.

Of great importance is the use of silicon in the

steel foundry for the manufacture of steel without blowholes.

It is very well known that hard steel may be cast sound, but the difficulties of obtaining a sound casting increase when the metal becomes softer. It is also known that forging and rolling and other mechanical working can annihilate the blowholes or their effect, but the application of steel in a cast state is in most cases a good deal cheaper and easier than in a forged state, and in numerous cases forging the object would not be possible. Before the introduction of the Terre Noire process of producing castings free from blowholes, cast steel did contain blowholes and consequently behaved most treacherously and disagreeably in all respects.

It is not here the place to discuss the relative value of forging versus casting without subsequent forging, and attention will only be given to the manufacture of steel without blowholes.

Undvoidably the question presents itself—What are blowholes caused by? and we feel sorry to say that this most important question is not yet settled.

Two competent men, Pourcel and Dr Müller, hold different views, which we shall do best to set forth.

Supported by his large experience in steel-making Pourcel defends his reaction theory. He says blowholes are caused by carbonic oxide, which is the product of a reaction between the carbon and the oxygen. In the presence of silicon there is no reaction between the iron carbide and the iron oxide, and the product of oxidisation of silicon being a solid,

no reaction is visible, and instead of a gas, carbonic oxide, a solid, silica, is formed which is separated as an iron or iron-manganese silicate when this latter is present.

Dr. Müller, who carefully analysed gases obtained from ingots and castings treated with and without ferrosilicon, ferromanganese, and ferromanganese-silicid, comes to the conclusion that not carbonic oxide but hydrogen is the real cause of blowholes, and the beneficial effect of silicon is based upon the assumption that silicon greatly increases the property of iron (Fe) of absorbing hydrogen. The presence of hydrogen in pig iron, Bessemer steel, &c., is undoubted, the moisture of the air and fuel is its source, and the increased absorptive power by silicon may be put in line with the fact that water can contain more carbonic acid when it is calcareous than when pure. In short, whatever gas may be the principal cause of the blowholes, a fact is that addition of silicon suppresses the evolution of gases.

According to Allen, silicon is not implied in sound castings, as at the Bessemer steel-works the final addition is only spiegel or ferromanganese, thoroughly mixed by his mechanical agitator. Pourcel thinks that manganese and not silicon increases the absorbing power of steel for gases. On the other hand, Dr. Müller admits the value of manganese for sound castings, but explains the beneficial effect by saying that the violent development of carbonic oxide expels the absorbed hydrogen

and nitrogen gas.* No doubt in this way all hydrogen and nitrogen may be got rid of, but that is not sufficient.

Prof. Ledebur has drawn attention to the law in chemistry that the more diluted solutions are the slower reactions take place, and thus explains how, in a liquid mass of steel, carbon and oxygen (carbide and oxide of iron) may be, and actually are, found together, and that a bath absolutely free from carbon has never been made yet. As certain is it that as long as the metal is liquid a reaction between carbon and oxygen will take place, provided there is no silicon to protect the carbon, and thus after the expulsion of hydrogen and nitrogen there will gradually come carbonic oxide in place of it. The beneficial effect of silicon and manganese, viz. of silicospiegel or ferromanganese silicid, is thus easily understood. One danger there is in its use, that is, the amount of iron oxide to be reduced is unknown, thus the exact amount of deoxidising agent cannot be fixed either, and for fear of too little it will be added in excess, which, however, may in some cases give an undesired amount of silicon or manganese, or both, in the steel. Another drawback against silicon is that it causes more shrinking, which may lead to internal

* An easy experiment will prove this: dissolve a gas in water, blow air through it, and all former gas will be replaced. In analytical chemistry the same is sometimes applied when in a liquid sulphurated hydrogen has been precipitating and has to be got rid of. A current of air blown through it drives out *all* H_2S afte some time.

strains. The foregoing considerations show that the application of silicon to obtain solid castings involves great practical skill both in making the bath and in its casting.

So much more agreeable is it to obtain such good results with it as are daily obtained at the Bofors steel-works where the most different objects are cast from steel without blowholes, such as propeller blades and propellers (to 14 feet in diameter), gun carriages for marine and land guns, hydraulic pressure cylinders, railway crossings, stern-frames (e. g. one of 32 feet greatest length), rudders, prow-frames, and numerous other objects, all of which give thorough satisfaction in all respects. All these, made by the open hearth process from pure Swedish charcoal pig and pure Lancashire scrap, cannot be but of a very superior quality. Seeing that excellent English and foreign tool steels often contain 0·4–0·5 per cent. silicon, and that Krupp's gun steel contains 0·1–0·3, &c., there is an agreeable confirmation of older practice by newer experiments. Crucible steel, considered the very best steel that can be wished, invariably contains over 0·1 per cent., generally over 0·3.

Very interesting are the experiments of Dr. Müller as regards crucible steel.

Numerous experiments performed in different places (Sheffield, Kapfenberg, Reichenau, Duisburg, Döhler) show without exception an increase in silicon and a loss in manganese of the charge before and after melting; also Brand's experiments show

the same, thus all pointing to one fact—crucible steel is almost always higher in silicon than either open hearth Bessemer, or any other steel.

Though almost all analyses of mild steel for structural work, i. e. bridge steel, ship steel, in form of plates, angles, tees, &c., rails, tires, and other railway material, and boiler plates, show not more than 0·01–0·10 per cent. silicon, it is not proved thereby that a higher amount would do harm, in fact that low silicon point is merely due to their mode of manufacture.

As we have said, to obtain a solid ingot, silicon is desirable, but then for all rolled articles such as above named, a little honeycombed ingot is often preferred to a solid one, as it behaves better under the rolls, and as the blowholes can be neutralised by mechanical treatment such as rolling, hammering, &c.

Thus, unless the casting as such is the end-product, there is no occasion for silicon to get into the bath. In one instance practice has shown that silicon has not to be more than about 0·2 per cent., that is for rails, especially if destined for cold countries, unless much manganese is present as well, because silicon makes steel sensitive to repeated shocks and extreme cold. In a word, in ordinary commercial articles there is neither a cause for silicon to be present in more than 0·2 per cent., nor is there any reason why it should be added purposely.

In steel without blowholes silicon will almost always be present in more than 0·3 per cent., but considering the acknowledged superior quality of

crucible steel there is no reason for fear. It hardly needs mentioning that when silicon does no harm in crucible steel neither does it in first class open hearth steel of the same composition.

PHOSPHORUS (P).

Metallurgical Behaviour.

The reduction of phosphorus from its compounds is a very easy thing, and besides, its affinity for iron being very great, there is no wonder that in the blast furnace nearly all phosphorus of the burden, that is of the ore, fuel, and flux, passes into the pig. About 90 per cent. of the quantity is thus taken up by the iron, and there is no means of getting rid of phosphorus in the blast furnace.

Some of the phosphorus may pass into the slag and form a compound with oxide of calcium that is unreducible by carbon, not even in presence of iron (this is the so-called four-basic calcium phosphate, $(CaO)_4P_2O_5$), and the amount of phosphorus thus taken up by a certain basicity of slag depends further on the temperature and the fuel: the higher the temperature and the more fuel, the more phosphorus will go into the pig. As most ores contain phosphorus so do most pigs, as is only too well known.

The ease with which phosphorus is reducible from its compounds is the reason why there is not the least

difficulty in making phosphoric pig, such as is wanted for the basic Bessemer process. In basic steel-works there is always plenty of phosphoric slag which is simply smelted together with the ore, as few ores contain enough phosphorus of themselves to give a proper basic Bessemer pig with 2·5–3 per cent. phosphorus. The manufacture of rich ferrophosphor has, so far as I know, not come into practical use, which is not at all surprising when one considers the facility of making a basic pig of the proper composition.

It may be remarked that though charcoal contains much less phosphorus than coke, the amount may sometimes be larger than is commonly thought, and not seldom exceeds 0·05 per cent. To get the phosphorus down to 0·01, charcoal is the only fuel that can be used, but not only must the ore be nearly free from phosphorus but the charcoal also must be choice.*

In ordinary remelting processes part of the phosphorus may be separated by lime; a greater part of it however by special purifying processes, such as treatment with iron or manganese oxides, &c. Phosphorus readily forms iron phosphates, hence when oxidised and given a chance to unite with iron oxide it eagerly does so.

* Very interesting analyses are communicated in 'Jern Kontorets Annaler,' 1888, by Profs. Nordenström and Särnström, regarding this question. They showed that charcoal from leaf-trees contains 4–5 times as much phosphorus as that from conifers, that the phosphorus depends on the nature of the soil, season of felling, &c.

Since the introduction of the basic process, which is essentially separation by lime, all others are put into the shade.

Predecessors of the Bell-Krupp process of washing the pig with Fe_3O_4 have been the iron-making processes in low hearth and puddling furnace. In both of these a low temperature and a rich ferrous slag (Fe_3O_4) prevail, thus favouring a separation of phosphorus. For all phosphoric pig not worked to basic steel or used in the cast iron foundry the puddling process is the way, unless some purifying process is adopted.

As is now known, the elimination of phosphorus is impossible in an acid-lined vessel, and the percentage of phosphorus in the charge of an acid-lined Bessemer converter is rather increased (though only apparently, because the other elements decrease). In the basic Bessemer process phosphorus plays the part of heating element, as mentioned before, each per cent. of phosphorus giving a rise in temperature of about 169° C. The disappearance of phosphorus however is, unlike silicon in the acid process, quite at the end, that is after silicon, manganese, and carbon have for the greater part disappeared. The prolonging of the blow is called the after-blow. Phosphorus is then oxidised and separated by lime, forming a calcium phosphate, and in this way 95 per cent. or more of the phosphorus is eliminated.

In the open hearth process, heat being applied from without, there is not a certain quantity of phosphorus that is wanted to finish the bath, and any pig will

dephosphorise when circumstances are favourable. Not only phosphoric pig is treated in a basic lined hearth, but also an ordinary pig may be finished to steel, and thus give a steel exceptionally low in phosphorus. This practice, followed in the Cocquerill Works in Seraing, will be suited for high class material only because the acid process is much cheaper, consuming a good deal less fire-proof material. There is no need to speak of phosphorus in the crucible process, as it is evident that for this very expensive process phosphoric material is never to be used.

Influence of Phosphorus on Pig Iron.

Phosphorus causes the carbon to be in the combined state; however, its influence in this respect is not intense. The melting-point of pig is lowered by phosphorus and it considerably increases the fluidity. In a high degree phosphorus has the tendency to liquate to the part that is longest fluid.

Phosphorus is a most important element to know in quantity, because it often fixes, or better said, excludes the use of the pig for a certain process. Phosphorus seems to expel silicon and sulphur, that is, ferrophosphor is generally low in silicon and sulphur, but ordinary basic pigs do not show this property, which is rather a pity, as none of those two named elements is wished in basic pig.

Ferrophosphor with 10 per cent. phosphorus is magnetic, but at 16 per cent. only slightly attracted, to become non-magnetic at 26 per cent. phosphorus.

Influence of Phosphorus on Cast Iron.

The property of imparting fluidity is advantageously made use of in the foundry, and here phosphorus is a good help for thin castings and especially for ornamental castings and pottery. For these latter, where only very little strength is demanded, 1 to 1·5 per cent. phosphorus may be present; such an iron will fill up the mould very well and give clear and solid castings. Of course this figure must be much lower when strength is wanted, but still for a dead load, such as applied to columns, even 1 per cent. phosphorus is permissible, though perhaps less is preferable.

Of great influence is the α carbon on the effect of phosphorus; the more α carbon the less phosphorus may be present, thus e. g. in the case of chilled castings which have 1–1·5 per cent. α carbon, the phosphorus must be kept under 0·3 per cent., whereas in ordinary castings with say 0·5 per cent. α carbon, 1 per cent. is allowable. Silicon causing the carbon to be as β carbon evidently allows of more phosphorus, and thin castings always containing much silicon (otherwise they would turn white, cooling so much quicker than big castings), this is a reason the more for phosphorus to be allowed in certain castings. The tendency to cause α carbon and thus to impart hardness does not tell much against the strong contrary tendency of silicon.

Influence of Phosphorus on Wrought Iron.

Wrought iron made from phosphoric pig will contain the more phosphorus the quicker the process of converting was and the higher its temperature, as made clear in a former chapter. Thus low hearth iron will be lower in phosphorus than puddle iron. Best Swedish bar iron contains about 0·02–0·04 per cent. phosphorus, either low hearth or puddle, because both fuel and pig are very pure in that country. English puddle iron contains 0·1–0·25 per cent. phosphorus, and we may assume 0·3 per cent. to be the maximum allowed as phosphorus causes cold-shortness and intensely affects the forging qualities, not so much by itself as because it lowers the melting-point, and the height of this point being a great factor in the forgeability it will be understood that any element lowering the melting-point will also diminish the forging quality; besides, phosphoric iron does not stand the fire well.

As has been said, carbon is a function of the influence of phosphorus, and to what extent may be judged from the fact that in soft wrought iron 0·4 per cent. phosphorus may be allowed, whereas 0·04 per cent. renders hard steel useless.

Wrought iron having but traces of manganese, thus misses the advantages of manganese on phosphoric metal. It is said that there may be 0·3 per cent. phosphorus in low carbon iron (that is, of course, not in steely iron or puddle steel), and the high repu-

tation Swedish bar iron has for its purity is chiefly valued by those who convert that iron to steel, and most especially tool steel, which is so very sensitive to phosphorus. For that purpose Swedish iron remains unrivalled.

Influence of Phosphorus on Steel.

The mere idea of phosphorus in steel makes one feel uncomfortable; however, excepting the hard steels, phosphorus is not *so* bad as thought, at all events it can be partly neutralised by other elements.

We have seen already how the influence of phosphorus rapidly increases with the carbon; this may be illustrated by another example. As already said, tool steel seldom contains more than 0·02 per cent. phosphorus, whereas rail steel may have 0·1 per cent., and under certain conditions even as much as 0·4. It is true both steels have quite different duties to perform, but undoubtedly 0·1 per cent. phosphorus in a hard steel would be fatal for whatever purpose it might be used. Phosphorus increases the ultimate strength to a degree about one-fourth of carbon: thus 0·1 per cent. phosphorus more or less causes a rise or fall of 1·5 kg. in the breaking load; a maximum lies at about 0·3–0·4 per cent., but the elastic limit rising more quickly, any increase in phosphorus will diminish the ductility, hence phosphorus makes steel brittle.

The elastic elongation is greater for phosphoric steel, that is the modulus of elasticity is smaller,

which means that phosphoric steel is not rigid, not stiff. The non-elastic elongation is much less for phosphoric steel.

The resistance to impact is lowered * by phosphorus, and so is the crushing strength.

The brittleness of phosphoric steel is not shown at a red heat—thus this is not the cause of the decrease in forgeability, but here it is again the lowering of the melting-point that hinders the forging: phosphoric steels have to be forged at a low heat, and hammering till the object is cold diminishes the coldshortness.

The rolling property is affected unless much manganese is present. The Edgar Thomson works found a steel with 0·35 per cent. phosphorus, 0·1 carbon, and 0·65 manganese to roll very well, also to forge well. The Terre Noire works made a series of experiments which showed that a rail containing 0·4 per cent. phosphorus, 0·3 carbon, and 0·8 manganese offers a tensile resistance of 55–60 kg. and an elongation of 20–25 per cent.

The lower the carbon point the later coldshortness will be caused by phosphorus. The hardness is somewhat increased by it. The said beneficial effect of manganese on phosphoric metal at first sight seems not in accordance with the fact that ingot metal, though almost always containing manganese, stands more phosphorus than weld metal that

* Records that phosphorus is especially good for steel objects which have to bear heavy shocks seem to be without any ground.

rarely contains manganese. On closer examination an explanation is at hand. Ingot metal, which we have called steel, is granular, never fibrous, however low its carbon point may be, and weld metal is fibrous, and phosphorus having in a high degree the property of causing the structure to be coarsely granular, and whilst in weld iron the presence of slag (not seldom it contains 2 per cent.) acts strongly to cause fibre, it is clear that this double reason causes steel to be much more sensitive to phosphorus than iron is. Though there need not be any surprise that iron stands more phosphorus than mild steel, there are, as far as I know, no comparative results of coldshortness trials of phosphoric iron and phosphoric steel of the same carbon point.

Of less importance is it that phosphorus, being more electro-negative than iron, counteracts rusting, and that the melting-point is lowered and the fluidity increased by phosphorus. Physical properties such as magnetism, density, &c., have been little investigated, and whether phosphorus affects hardenability is not at all settled. It is known that in steels taking temper, phosphorus is a deteriorating element, but whether they take less temper is not known.

I think it might be again mentioned that although phosphorus is very intense in its influence on tool steel, 0·01 per cent. may without the least fear be present, and there is consequently not the least harm in calling 0·005, 0·01, or 0·004 per cent. 0 per cent., because in thousandths of a per cent. the influence is

not known at all, and so long as this remains so there is no need to give analyses in three decimals —so much the less reason is there to give them in four decimals. Quod absurdum!

Uses and Occurrence of Phosphorus.

The proper use of phosphorus is in the basic Bessemer process where a 2·3 per cent. phosphorus is required to give the heat. The amount of phosphorus wanted is dependent on the silicon present, and 1·56 per cent. phosphorus being equal to 1 per cent. silicon, more phosphorus is demanded in the basic process than silicon in the acid process. Although for basic pig 0·5 per cent. silicon is most suitable, most brands contain more. How unsuited more than about 0·5 per cent. silicon is in basic pig becomes clear when it is called to mind that first it has taken more fuel in the blast furnace, then it takes more lime to dephosphorise and eats the lining of the vessel.

Best basic pig from Peine contains 3 per cent. phosphorus, 0·5 silicon, 2·2 manganese; Hörde, 1·5–2·5 phosphorus, 0·4 silicon, 2·2–3 manganese; Le Creusot, 2·5–3 phosphorus, 1·3 silicon, 1·5–2 manganese; Witkowitz, 3·5 phosphorus, 0·11 silicon, 1·16 manganese; Ilsede, 3·3 phosphorus, 0·11 silicon, 3·8 manganese; Middlesborough, 2·75 phosphorus, 1 silicon, 1 manganese. Next in phosphorus contents come the foundry pigs: these are sometimes pretty rich in phosphorus which, we repeat, is favourable to fluidity. Coltness, Clarence, Cleveland,

Langloan, &c., contain about 1 per cent. phosphorus, also Hörde, Phœnix, Union, &c. Much lower in phosphorus are the French pigs from the French works, Terre Noire, St. Louis, Firminy, Micheville, &c., which have only 0·04–0·07 per cent. Lowest of all are the Swedish charcoal pigs from Finspong, Bofors, and others, viz. trace–0·05 per cent.

All pigs which are intended to be converted into wrought iron in low hearth or puddling furnace may contain 1 or 1·5 per cent. phosphorus, as the greater part of it is separated by the slag rich in iron which is made with those processes. White forge irons from Cleveland, Luxemburg, &c., have about 1 per cent. phosphorus more; Dowlais, Yorkshire, Firminy, Marnaval, Micheville, about 0·6; lowest again the Swedish Finspong, Bofors, &c., with 0·01–0·02. Bessemer pig does not allow of much phosphorus as none is eliminated, and, as, before said, the resulting steel is more sensitive to phosphorus than wrought iron. Bessemer pig may hardly contain above 0·1 per cent. phosphorus, this being the limit for rail steel, but 0·05, as in the English hematite, will do for most purposes.

The same may be said for the open hearth process, as in that also no elimination takes place.

In Seraing even hematite pig with 0·05 per cent. phosphorus is treated in a basic lined hearth, and the resulting steel then contains 0·01–0·02 per cent. phosphorus instead of 0·05–0·06 as it would have if treated in an acid-lined hearth.

Bofors open hearth steel (acid furnace) does not

contain above 0·05—generally below 0·03 per cent. phosphorus. Boiler-plate steel from Motala, 0·03 per cent. phosphorus; Peine (basic), 0·05. Bridge steel, Kladno, 0·03; Phœnixville, 0·05; Forth Bridge, 0·05. Ship steel from Seraing, 0·01–0·04; Obouchoff, 0·01. Rails from most works, 0·1—such as Krupp, Edgar Thomson, &c. Tires, being richer in carbon, generally below 0·08. Gun steel from Krupp, Bofors, &c., 0·04; from former also 0·01 or traces; Trubia, 0·01; Terre Noire, 0·07. Rifle steel from Fagersta, 0·03; Solingen, 0·08; Firminy, 0·07.

Tool steels, such as are used for finer tools, contain from traces of phosphorus to 0·02 per cent.; this latter amount may be considered harmless. Tool steel from Holtzer contained 0·03 per cent., but comparative experiments with steels do not show any deteriorating effects.

Agricultural steels often contain 0·05 per cent. phosphorus.

It may be further mentioned that cast iron for guns from Finspong contains traces only of phosphorus; from Åker (Sweden), 0·07; American, 0·17–0·2; Woolwich, 0·7.

SULPHUR (S).

Metallurgical Behaviour.

Sulphur is found in most iron ores, is easily reduced, and has an unlimited affinity for iron. Still more sulphur than in the ore is found in the fuel, with the exception of charcoal; and if it were not for the fortunate circumstance that sulphur can be separated in the blast furnace, the whole process of steel and iron making would never be what it is now.

However great the affinity of sulphur for iron, it has a still greater affinity for calcium, and the resulting calcium sulphide being insoluble in the molten iron nearly all sulphur (up to 90 per cent.) can be eliminated by an addition of lime to the burden.

There seems to be a basicity of the slag at which no more calcium sulphide can be taken up, as instances are known of works smelting sulphurous ores and unable to get an iron free from sulphur, not even by continuing to increase the percentage of lime in the cinder. Be this as it may, other reasons tell against a too basic slag, and if the ore is too sulphurous it has to be roasted off in order to separate the greater part of the sulphur. When the ore contains over 1 per cent. sulphur, roasting will prove best, and the sulphur can be brought down to about 0·5 or 0·2 per cent. Lower than 0·2 per cent. is hardly wanted, though a Westman roasting

kiln may bring it down to 0·05 or 0·02. A further treatment with water, to dissolve the sulphates, is a means of getting the sulphur down to about 0·1 per cent., but it is too costly. When the roasting has been performed at a yellow heat lixiviation is of no further benefit.

As to the fuel, best Durham coke contains about 0·8–0·5 per cent. sulphur; ordinary coke, 1–1·5; raw coal more, and anthracite coal still more. Charcoal, on the contrary, seldom contains more than traces, and also many good cokes have no more than 0·3–0·5 per cent. sulphur.

Manganese in the blast furnace greatly adds to the separation of the sulphur, and one more fortunate circumstance is that the higher the temperature the more sulphur goes into the slag, hence hot blast favours sulphur separation.

Knowing then that once you have got sulphur in your pig you will never get it out again, it is easily understood of how much importance it is to get rid of it in the blast furnace. In this respect sulphur is opposite to phosphorus: in the blast furnace phosphorus cannot be eliminated, but on further steel-making it is easy to separate 90–95 per cent. of it; whereas sulphur can be separated for 80–90 per cent. in the blast furnace, but to eliminate sulphur in the basic process is, though possible, far too costly and only to be done to a limited extent.

In the cupola a desulphurisation may take place when there is much lime added as a flux; however, though less harmful in cast iron than in steel, sulphur

may always be looked upon as a most unwelcome guest. If too little lime is added in the cupola the sulphur will increase, as the iron will take up sulphur from the melting coke.

In the acid Bessemer converter no sulphur is separated, neither in the open hearth nor crucible process, as is quite natural. In the basic process, where the oxidised sulphur is given opportunity of uniting with a base, sulphur can be eliminated; however, its burning does not start before nearly all other elements are gone. Its separation is effected by the so-called over after-blow, but by this over after-blow such a tremendous amount of iron gets oxidised, all its protectors (silicon, manganese, carbon) being burned off, that the waste is very great; besides, a greater quantity of final addition has to be made to deoxidise the bath, and as spiegel-iron would give a too hard product, rich ferromanganese must be used.

Different considerations have led to the opinion hat desulphurising is not economical. The Bell-Krupp method of dephosphorising, washing with iron oxides—especially Krupp's, who uses manganiferous iron oxides—gives also good results as to desulphurising; and so does Rollet's process—treatment in a cupola with lime and fluor-spar; but the cheapest of all will always be to prevent the sulphur coming into the pig in the blast furnace.*

* Patents taken out for desulphurising with lead oxide (5 parts of the latter to 1 part FeS_2) need mentioning to show the absence on thought of some people.

Influence of Sulphur on Pig Iron.

Whilst pig iron with 3 per cent. phosphorus or more can be used very well, a pig with more than 0·5 per cent. sulphur is good for nothing and in most cases 0·1 per cent. is too much, and it is best to keep the sulphur under 0·05 per cent. In steel-making pig 0·02–0·03 per cent. is allowed. Sulphur diminishes the taking up of carbon and has a strong tendency to keep the carbon as *a* carbon; thus in one respect it is like silicon, in the other like manganese.

Pig with notable quantities of sulphur, such as 0·1 per cent. or more, will be white. White pig is always richer in sulphur than grey, and this for two reasons. Turner pointed out how decrease in silicon and increase in sulphur go hand in hand, also the higher temperature of the grey iron, which also means a higher amount of silicon and less sulphur. A low temperature gives white iron poor in silicon and richer in sulphur. Percy's experiments proved that when melting together an iron sulphide with iron rich in silicon, sulphur is expelled.

Prof. Ledebur thinks the basicity of the slag of more importance than the quantity of sulphur in ore or fuel, hence it is not rare that charcoal iron is richer in sulphur than coke iron, because a charcoal slag has a much lower basicity. Many coke irons contain 0·02 per cent. sulphur only, or even traces, whilst most charcoal irons contain more than 0·05, some 0·1.

Knowing the willingness of manganese to slag sulphur, and the basicity of the slag in a furnace running on ferromanganese, it is evident that ferromanganeses will be exceptionally low in sulphur.

English pigs are on the whole much higher in sulphur than German ones, which seldom have over a few hundredths of a per cent. Sulphur has the property of driving out carbon from the pig. By increasing the sulphur the carbon can be completely driven out. Iron sulphide and iron carbide do not unite.

Influence of Sulphur on Cast Iron.

Sulphur makes the iron pasty and thus gives rise to blowholes. Also the property of giving white castings is rather undesired, except in special cases, e. g. 0·1–0·15 per cent. sulphur was purposely added in cast iron for guns in Finspong. It is doubtful whether it is due to the sulphur that those guns enjoyed a good reputation—it is more likely due to the fact that sulphur causes less carbon to be present and more *a* carbon. It is said that 0·1–0·2 per cent. sulphur does not diminish the strength of cast iron, but cast iron is so complex a body that a definite opinion of the influence of some 0·1 per cent. of anything can hardly be formed.

The influence of sulphur to keep carbon as *a* carbon is stronger than that of silicon to make it β carbon, which property combined with the fact that sulphuric irons are low in silicon, makes sulphur an unwelcome element.

Influence of Sulphur on Wrought Iron.

Sulphur makes iron redshort so that forging, rolling, &c., become difficult or impossible unless performed at a white heat.

Iron is more sensitive to sulphur than to phosphorus; 0·02 per cent. sulphur causes redshortness and 0·04 per cent. renders the metal good for nothing. It is true that phosphorus has a worse reputation, but this will very likely be on account of its occurring more frequently.

Influence of Sulphur on Steel.

As it is known that sulphur has a deteriorating effect on steel, and that it can hardly be separated in any steel-making process, but easily in the blast furnace, sulphur has always been an unimportant element—hence very little is known of it in definite figures. Few steels contain more than 0·05 per cent. sulphur, but it seems that even 0·1 per cent. can be tolerated if there is a good quantity of manganese present. The influence of the carbon point on the effects of sulphur is not yet ascertained, but manganese has a very marked influence.

Whereas 0·04 per cent. sulphur renders wrought iron completely useless, as much as 0·1 per cent. may be present in steel without interfering with the rolling property; this difference is due to the fact already mentioned that the first is practically free from manganese and the second invariably contains it. To the same cause may be attributed the said

property of hard steels to withstand more sulphur than mild ones. Sulphur, as also before said, increases the rusting of steel.

Uses and Occurrence of Sulphur.

The only case when a real sulphide of iron is made use of is in the above-mentioned manufacture of cast-iron guns at Finspong. In all other cases sulphur may be considered an impurity whose presence is a necessary evil. Mild steel for bridges, boilers, &c., contains from traces to 0·06 per cent. sulphur. The exceptionally high sulphur in bridge steel from Phœnixville, viz. 0·12 per cent., does not seem to do harm, the metal possessing 40–47 kg. tensile strength, 25–30 per cent. elongation, and 50–60 per cent. contraction.

Rail steels show little variation in sulphur, mostly about 0·07–0·15 per cent. When sufficiently high in manganese 0·15 per cent. sulphur does not interfere with the quality. Finnish manganese rails containing 0·73–1·4 per cent. manganese and behaving very well under traffic, contain as much as 0·6–0·22 per cent. sulphur.

For ordnance steel the sulphur had best be kept under 0·05 per cent. Most gun steels contain from traces to 0·02 per cent. Whether more than 0·02 would do any harm is doubtful; however, gun steel being of a more select kind there is not much chance for sulphur to slip in.

COPPER (Cu).

Metallurgical Behaviour.

Copper being more easily reducible and less oxidisable than iron, and readily forming an alloy therewith, will be found in the iron when the burden contains copper and will never by any oxidising process be separated. Copper often occurs in the ore, especially those which contain sulphur, and the greater part of it passes into the iron, hence many pigs contain copper—and very likely many more have always done so, only nobody has looked for it. Nowadays pig is often tested for copper also, though very little is as yet known about it. As neither reducing nor oxidising processes can possibly do anything for its elimination it will have to be found in the composition of the blast furnace cinder, if its passing into the pig iron is to be prevented. The slag has to be silicious so as to form a copper silicate—no easy thing in the presence of much sulphur. Difficulties might arise, but fortunately the amount of copper in iron ore is generally little or none. Once in the pig the copper will remain through all processes.

Copper in Pig Iron.

Though spiegel-iron and ferromanganese are highest in copper contents there is less reason to think that manganese facilitates the alloying than

that the basicity of the slag is the cause, the chemical character of copper demanding an acid slag to be scorified. It would be very interesting to know the quantities of copper in different ferrosilicons. Ayresome ferrosilicid, 12 per cent. silicon, contained 0·01 per cent. copper, but so did a silico-spiegel with 12 per cent. silicon and 19 per cent. manganese. Surely so much as 0·37 per cent. copper, as in a 77 per cent. ferromanganese from Phœnix, will belong to the exceptions. Seeing that Krupp's spiegel-iron contains 0·16 per cent. copper, Vulcan 0·12, Siegen 0·5, ferromanganese from Hoerde 0·17, from Rechitza 0·14, and that many pig irons contain copper in notable quantities (Coltness 0·1 per cent., Clarence 0·04, Union 0·04, Hoerde 0·09, Terre Noire 0·26, Rechitza 0·24), it may be concluded that some tenths of a per cent. do no harm. Though a charcoal furnace slag is, as a rule, very acid, many charcoal pigs contain copper, e. g. Diosgyör with 0·32 per cent., Krompach 0·34, Ilsenburg 0·1, &c.

Though it would be of interest to know the influence of furnace conditions on the quantity of copper taken up, there is as yet no information available.

Copper in Cast Iron.

Profs. Ledebur and Percy agree in thinking 0·2–0·28 per cent. copper harmless in cast iron. Percy considered that amount rather an improvement. One per cent. of copper renders the iron hard, probably on account of its influence in keeping carbon

as *a* carbon, in which respect it resembles sulphur, though in a less degree.

Copper in Wrought Iron.

As to the influence of copper on the properties of wrought iron not the least reliable information is to be had.

Copper in Steel.

Though opinions about copper in steel have differed, later experiments carried out by Wasum have plainly shown how undeserved the bad name of copper in this connection has been. In America 0·15–0·2 per cent. copper in steel is considered quite too much. Prof. Eggerts asserted that 0·5 per cent. copper renders steel useless, but Wasum found a steel with as much as 0·86 per cent. copper not to show any sign of redshortness.

Wasum added copper as such to a Bessemer steel charge (three tons converter) before the blow was started and tested the metal for its qualities. He found that not only 0·86 per cent. copper steel (with 0·23 per cent. carbon, 0·71 per cent. manganese) did not show any redshortness, but even 0·85 per cent. copper, together with 0·11 per cent. sulphur (in steel with 0·31 per cent. carbon, 0·51 per cent. manganese) did not prevent rolling the steel.

He found further that 0·04 per cent. copper and 0·16 per cent. sulphur rolled well, but 0·43 per cent.

copper rolled badly, being redshort. The action of copper on redshortness seems to be stronger in the case of hard steel, the intensity of copper in this respect being about $\frac{1}{8}$ of the sulphur. It is to be expected that manganese allows of more copper being present without causing redshortness.

Wasum's investigations are fully confirmed by Chombley's, who experimented in Firminy with a 10-tons open hearth and found steel of the following composition to roll very well and not to show any redshortness. The steel contained 0·5 per cent. copper, 0·5 carbon, 0·45 manganese, 0·2 phosphorus. As much as 1 per cent. copper (and 0·07 per cent phosphorus) did no harm. These facts show that the tale that a workman might spoil a steel bath by throwing a copper coin into it has no truth in it.

Copper gives hardness and higher figures for tensile strength, but no definite figures are known. Longmaid took out a patent for the addition of 0·06–0·09 per cent. copper, but we have not heard of its application and doubt that so small a quantity can have any influence.

Uses and Occurrence of Copper.

As far as we know, the use of copper is restricted to the steelworks of Le Creusot, where an addition of 2–4 per cent. in steel for armour plates and other ordnance material was said to be made.

Few analyses speak of copper, hence but meagre information can be had. Rails from Krupp, Hoerde

Phœnix, Rechitza showed 0·14 per cent. copper. We have said that Krupp's spiegel-iron contained 0·16 per cent. copper; his gun steel contains 0·25–0·35; a tire, 0·2. A railway crossing from Bochum contained 0·26.

When we know that Krupp's undisputedly high class steel sometimes contains 0·35 per cent. copper, any fear on account of some tenths of a per cent. copper appears to be groundless.

CHROMIUM (Cr).

Metallurgical Behaviour.

Chromium belongs to those metals whose oxides are very difficult to reduce, in fact to reduce copper from Cr_2O_3 by carbon requires the highest heat obtainable, like manganese, though Cr_2O_3 is somewhat less difficult to reduce than MnO_2.

Some properties of metallic chromium may be mentioned here, as the same are found again in chromium compounds.

Chromium is very difficult to melt, more so even than manganese or platina. It is very hard, somewhat like the mineral corundum; its density is lower than iron, varying between 6·8 and 7·3.

Chromium combines readily with carbon, sulphur, iron, aluminium, phosphorus, &c. Presence of iron thus facilitates the reduction of chromium, so that it

can be performed in a blast furnace. The metal occurs generally as a double oxide of chromium and iron, the chrome-ironstone containing sometimes 60 per cent. Cr_2O_3 and 20 per cent. iron oxides, but generally no more than 50 per cent. of the former. Pure Cr_2O_3FeO contains nearly 68 per cent. Cr_2O_3, or about 46 per cent. chromium, so that 65 per cent. chromium pig is the theoretical limit for manufacture in the blast furnace; the practical limit is about 40 per cent. chromium.*

It hardly needs mentioning that the quantity of fuel consumed is enormous, as in the case of rich ferromanganese. Three tons of fuel are used per ton of pig, and a hot blast and high blast pressure are also conditions to be fulfilled. A troublesome circumstance is the difficulty with which the oxide of chromium is scorified, practically only by alkaline carbonates, fluor-spar, borax, or lime in great excess.

Rich ferrochromes have to be made from other material, i. e. from Cr_2O_3; this, however, requires several chemical processes for its production, and hence is rather dear.

Experiments of my own led to the discovery that Cr_2O_3 may easily be obtained from a waste product, but the use of poorer ferrochrome will always prevail over the use of richer ones, i. e. that made in the blast furnace will always be the more economical to use.

Knowing the extreme ease with which chromium is oxidised, and that its oxide does not slag, it is

* According to Brüstlein, 60 per cent.

easily understood that chromium pig is used in no process of steel-making, and that when wanted in the final product it has to be added after the process is finished. An attempt to puddle chromium pig could but end in failure, and so will any other trial, because in any oxidising process the chromium burns at once, and its highly refractory oxide intervenes between the iron molecules, and, not being liquid, cannot be squeezed out. The addition of ferrochrome is of great benefit to the final steel.

Chromium in Pig Iron.

The manufacture of chromous pig is not new, but the manufacture of richer chromium pig for addition to chromium steel is of quite recent date. Bertier was the first to make ferrochrome in crucibles (1820), and at Brooklyn in 1869 ferrochrome containing 21–46 per cent. chromium (?) has been made. The Tasmanian Iron Co. smelted pig in the blast furnace with 6·7 per cent. chromium, and at Medellin the same was done with pig containing 2·4 per cent.

In 1875 Brüstlein introduced the manufacture of ferrochrome in the steel-works of Jacob Holtzer in Unieux, and it is from him that most information is to be obtained. Since the excellent properties that chromium imparts to steel have been known, numerous works have followed the example of Unieux. Terre Noire, so well known for its ferro-manganese, smelts ferrochrome in the blast furnace. In Sweden, where chromium steel is coming into

favour, the chromium pig is made by the Lyrholm Co. in crucibles, 60–70 per cent. chromium. At Unieux, current practice is to make a ferrochrome with 48–52 per cent. chromium, but in crucibles they have made a ferrochrome with 84 per cent. chromium.

The influence of chromium is in the first place to make the pig very difficult to melt, and to considerably raise the limit of saturation for carbon. In the chapter on Manganese we saw how this element raises the carbon, but this is done to a still higher degree by chromium. An 80 per cent. chromium pig from Unieux contained 11 per cent. carbon, whereas a 65 per cent. chromium pig from Adour contained 12 per cent. carbon. That the amount of carbon taken up is a function of the excess of carbon present in the crucible is suggested by the fact that a rich percentage of chromium does not necessarily mean an extraordinarily high carbon amount; besides, there seems to be a limit of chromium beyond which the carbon is lowered again: thus, for example, Holtzer, 84 per cent. chromium, 9 per cent. carbon; 82 chromium, 7·5 carbon; 80 chromium, 11 carbon; 72 chromium, 3·4 carbon; 60 chromium, 8·6 carbon.

Compared with other ferrochromes Holtzer's are rich in carbon; e. g. 5 per cent. carbon is found in Holtzer's 30 per cent. chromium pig, and in 67 per cent. chromium pig from Unidex; the Swedish brands are said to be lower in carbon. Richer in carbon than the Holtzer ferrochrome are those from

Adour; here 11 per cent. carbon is found in a 64 per cent. chromium pig. The proportion of silicon is also remarkable, running up to 8·2 per cent. in Holtzer's 82 per cent chromium pig, and to 2 per cent. in his ordinary ferrochrome (48–52 per cent. chromium). We do not expect ferrochrome manufactured in a blast furnace to be rich in silicon, seeing that a silicious slag would not be appropriate; but information is wanted.

Unlike ferromanganese, the crystals of which are developed in the breadth as plates, ferrochrome shows long white needles or very small plates, and the higher the carbon the more needles are visible on fracture, and the richer in chromium the smaller the size of the needles. The carbon seems to be altogether in the combined state, which may be due partly to the fact that chromium pig solidifies very rapidly.

A remarkable and unexpected fact is the very low specific gravity of ferrochrome, viz. about 6.

When chromium ore containing sulphur is smelted, as the Tasmanian Co. does or did, the resulting pig will contain sulphur, which can be separated by remelting the chromium pig with ferromanganese. Such treatment, however, will considerably raise its price.

Chromium in Cast Iron.

We do not know of any information about chromium in cast iron, but remembering the in-

creased cost, viz. more costly melting, difficult casting, thick fluidity, and the brittleness it imparts when much carbon is present, we cannot imagine any advantage in that direction. One of the chief advantages of cast iron being its cheapness, there cannot be any good in trying anything with it that will raise its price considerably. It might prove useful for chilled castings, but these, as they are obtained from the Grüson works, hardly want improvement.

Chromium in Wrought Iron.

Considering the above described behaviour of chromium and its oxide, it is not to be expected that it will ever enter into the manufacture of weld-metal.

Chromium in Steel.

The character of chromium steels is of great interest. We are indebted to the Holtzer works for the greater part of our knowledge on that subject. The influence of chromium on steel had long been known, but a series of experiments was wanting still and the communication of Brüstlein was very welcome to those interested in the subject. Chromium has a marked influence on the tenacity of steel: the maximum tensile strength is obtained with about 1·5 per cent. chromium, but then the steel containing much carbon also is rather brittle. More advantageously 0·5 per cent. chromium may be used.

Both ultimate strength and elastic limit are raised, and the elongation not diminished in the same degree as with carbon. Thus, for example, a steel containing 1·5 per cent. chromium and 0·7 carbon can show a breaking load of 72 kg., an elastic limit of 42 kg., and an elongation of 18 per cent. (in 75 mm.); whereas a carbon steel of the same ultimate strength would require to be hardened to possess such a high elastic limit, but would then have a much lower figure for ductility. When this said chromium steel is hardened the ultimate strength becomes 150 kg., the elastic limit 140 kg., the elongation 6·3 per cent. (75 mm.). Another chromium steel containing 2·2 per cent. chromium, 0·6 carbon, gave, after annealing, an ultimate strength of 70–75 kg., an elastic limit of 45–50 kg., and an elongation of 18–20 per cent.

Such figures cannot be obtained with carbon steels. The resistance to impact is remarkable, and this property is made use of on a large scale. Crushing strength being great, the transverse strength must be great as well.

A drawback to the general application of chromium steel is its great hardness, which renders tooling difficult and costly.

The casting of chromium steel offers difficulties: first, ladles, moulds, &c., must be of a highly refractory material, on account of the high melting-point of chromium steel, which means a very high temperature when molten. The steel solidifies very quickly, and all casting must be performed at a yellow heat, which again involves great shrinkage.

Though the natural hardness of chromium steel is greater than that of carbon steel (of same carbon point) and though the hardening property of chromium is still more developed in hardened steel, it is certain that chromium alone does not impart to iron (Fe) the property of taking temper.

We should explain this by saying that chromium possesses the property of keeping carbon in the form of "hardening carbon"; hence when the carbon is purposely kept very low (say under 0·03 per cent.)* quenching has no hardening effect, because, though all carbon is kept as hardening carbon, its quantity is too small to be felt, and chromium itself has not the same effect as hardening carbon.

Chromium does not interfere with the forging, on the contrary it seems to neutralise the effect of carbon, a chromium steel with 12 per cent. chromium and 2 per cent. carbon being forgeable, whilst, without chromium, 1·5 per cent. carbon is the limit for forgeability. A difficulty in forging is that the temperature of the piece must be kept as low as possible, because chromium steel does not stand the fire well, being liable to be burnt.

Chromium steel can be rolled quite as well as ordinary hard steel.

Of course there is no question of welding large pieces, but for smaller objects, such as edges and points of tools, it may be effected with the aid of

* To manufacture chromium steels of say 1 per cent. chromium and very low in carbon, say 0·03 per cent., would only be possible on an experimental scale, seeing the richness of chromium pig in carbon.

borax. Such tools are best suited for continual feed work.

The magnetism of iron is not destroyed by as much as 65 per cent. chromium.

The fracture of hardened chromium steel is extraordinarily fine.

Uses and Occurrence of Chromium.

Ferrochrome is used only as an addition to the ready made steel and perhaps iron (?), and can be got of every description up to 85 per cent. chromium. The necessity of using brasket crucibles for the very rich brands causes them to be very rich in carbon, which is rather a drawback, as chromium steels rich in carbon are brittle. Clay or other ordinary crucibles are eaten through, and special crucibles are too dear.

The blast furnace, which of course has to use chrome-ironstone as a raw material, cannot give a richer pig than 40–60 per cent. chromium, as a rule under 40 per cent.; this, however, will suit most purposes.

According to Dr. Leo, in Sweden, chromium pig is added in the puddle furnace (!) and cupola, also in Lancashire hearth. These statements, for well-known reasons, we rather doubt. He also asserts that chromium steel is used for rails. We do not know of any work producing chromium steel rails, but there is no other objection to its use than its high price (which is a somewhat serious one) Chromium steel rails will stand a very heavy drop

test, will wear very little, will be very strong and safe, but the price being so much higher they are not likely to come into use; a heavier section of rail at any rate will be far cheaper. The tires, which are always preferred to be of a harder material than the rails over which they run, would have to be of chromium steel as well. However, chromium steel does not seem to be fit for this, as it is sensitive to *repeated* shocks. For the same reason it will not do for railway carriage axles. Though good for ore-crushers and the like, it has, as compared with Grüson chilled iron, the drawback of being a good deal dearer and not superior to that iron. For rolls it will also be good, but for calibrated rolls the hardness will be an obstacle. This objection, again, is not met with in Grüson's calibrated chilled iron rolls. Thus, where hardness is the most prominent property demanded, chilled iron answers the purpose.

The most important application of chromium steel is for projectiles, and especially solid armour-piercing shot. Indeed chromium steel shot have done what was thought impossible before, and the great development in this branch may be judged from the number of steel-works manufacturing chromium steel projectiles.

After the startling fact that a 12-inch Holtzer projectile actually perforated a 16-inch Brown compound plate, the suitability of chromium steel for shot was established, and chromium steel projectiles now made by Holtzer (Unieux), Firminy, St.

Étienne, Terre Noire, Firth, Bofors, and many other works. The extraordinary resistance to impact, the great hardness and great general strength—i. e. strength to remain intact—and the absence of setting up, are four important items badly wanted in a perforating projectile. Hardened and tempered chromium steel possesses about 100 kg. tensile strength, thus there is no wonder it does very well for solid shot.

Armour-piercing shell, i. e. projectiles containing a relatively small bursting charge, made of chromium steel, necessitate the use of powerful explosives, otherwise they will either not explode, or if they do, in a few fragments only; besides, the percentage of chromium must not be too high. Hardened chromium steel seems to possess the most disagreeable property of bursting of itself on account of internal strains—hence, after the first success and rush after chromium steel shot, misgivings arose about it, and now it is often required in contracts that the delivered projectiles shall be stored for some time, and the acceptance of the lot will be according to their behaviour during storage and after trial. No doubt this difficulty will be overcome in practice, if it has not been already.

The hardening of chromium steel is much more difficult than that of ordinary hard steel; it very soon cracks, thus necessitating the use of oil as a cooling medium. The hardening has to be done equally all over and throughout the whole mass, and the tempering is best done all over the body as

well, because the point, being thinnest, has taken the highest temper and will keep it. In the case of a shell, the difference in temper of point and base can be obtained by heating the point somewhat more highly.

Chromium steel has not succeeded as a metal for armour plates. Where a hard armour plate is required, as when only few but very heavy blows are to be expected, as for coast batteries, Grüson's chilled iron stands remarkably well.

For gun-making the great hardness of chromium steel is a serious objection, for although a hard bore is a desideratum, so as to withstand erosion and the friction of the projectile, a too hard bore makes accurate rifling next to impossible. Whitworth hexagonal bore might prove useful here. The matter deserves examining, as a metal of 50 kg. elastic limit, 75 kg. ultimate strength, and 20 per cent. elongation is very welcome to gun-makers. Heavy guns would thus give a much higher efficiency per ton of gun, and light guns might have their weight reduced considerably (about one-half).

Another application of chromium steel is for tools; here 1·5–2 per cent. chromium, with about 1 per cent. carbon, will give a tool of extraordinary hardness which will replace the emery wheel in many cases. As chromium steel of such a high carbon point is brittle, it will not do for cold chisels, but does well for turning tools and drills. It would make good milling tools if it were not that its hardness renders it rather difficult to make so com-

plicated a tool as a milling tool. It is admirably suited for punches, mint dies, &c. Then unknown it was used long ago for the stampheads for crushing auriferous quartz, and was highly valued.

Razors made of chromium steel will cut glass, and as this steel takes a very fine damask, its use for swords is suggested. Safes may be made burglar-proof if manufactured from chromium steel.

It is said that the St. Louis bridge over the Mississippi is constructed of chromium steel of 70 kg. ultimate strength and 48 kg. elastic limit. Before applying a new metal to great works like a bridge its whole character should be thoroughly understood, and this is not the case with chromium steel as yet.

TITANIUM (Ti).

Metallurgical Behaviour.

Some magnetic iron ores contain titanic acid and the titanium will for the greater part pass unreduced into the slag. A minute part passes into the pig iron.

Many Swedish ores are titaniferous, for example those from Kirunavaara, Luoravaara, Gellivare, which sometimes show 0·5–2 per cent. titanic acid, those from Taberg containing 6 per cent. Norwegian titanate of iron may be found containing over 40 per cent. North Hasting (Ontario) has iron ore with 8–

12 per cent. of the same, whereas the Lake Superior ores used to be free from it. New Caledonia has chrome-ore with 0·8 per cent., and besides there is the bauxite that often contains some 5 or 6 per cent.

Fortunately, TiO_2 is difficult to reduce. The metallic titanium distinguishes itself by its affinity for nitrogen, wherein it resembles silicon and borium. The well-known copper-coloured cubes found in some blown-out blast furnaces are a compound of titan cyanide and titan nitride ($Ti(CN)_2 3Ti_3N_2$).

Free titanium is readily burnt when heated, thus in any oxidising process, if present in a pig, it will disappear at once.

Titanium in Pig Iron.

Though Percy asserted that titanium did not alloy with iron, and though many attempts to detect it in pig iron have failed,* it is now established that it does alloy with iron, and also that some pigs, notably from Clarence, contained 0·26 and 0·18 per cent. titanium. Cold blast Yorkshire also is said to contain traces, and so with Cleveland pig. Many Irish pigs contain from 0·5–1·6 per cent. The titanium seems to be present as a carbide, TiC, a known compound, and recently discovered by Skinner in pig iron.

Sefström obtained titanium-iron alloys by smelting together iron oxide and titanic acid at a very high heat. He obtained alloys of 4·78 and 2·2 per

* The determination of titanium in a large bulk of iron belongs to the difficult problems in analytical chemistry.

cent. titanium and 0·5 per cent. The first was hard but malleable, the second soft, the third non-malleable.

Concerning the influence of small quantities of titanium as met with in some pigs, nothing is known, but there need be no fear of its doing harm, as the amount seldom exceeds a trace. It is of much more importance to know the influence titanic acid has on the cinder. This causes a marked rise in the melting temperature of the slag and may eventually cause titaniferous ores to be of little value. The Ontario ore with 10 per cent. is hardly to be smelted. The smelting of the Swedish Taberg ore requires 2·5 times as much fuel as other ores free from titanic acid. What influence the high melting temperature of the cinder has on the quality of the pig will be understood when it is remembered that a high temperature in the blast furnace generally means a pig rich in carbon and silicon. Thus no doubt titaniferous ores may give a pig different to ordinary pig, though not caused by the presence of titanium in the pig itself.

Titanium in Steel.

Although Mushet himself was so thoroughly convinced of the beneficial effect of titanium on steel and iron that he took out thirteen patents to protect his invention; although others affirm titanium steel to be harder, stronger, and more ductile than other steel, titanium steel has not yet succeeded in making its way, and it is doubtful whether it ever will do so

TUNGSTEN (Wo).

Tungsten chiefly occurs in the mineral wolframite, a double tungstate of iron and manganese. The reduction of the compound is easily effected, and the metal tungsten, though impure, can be obtained cheaply enough.

Although the production of ferrotungsten can be carried out in the blast furnace, as shown by the Terre Noire Co., it is hardly to be expected that a furnace could be kept running on it, as its use is not extensive enough. The reduction can be performed at a good red heat and does not take much fuel, but the metal tungsten is then obtained in a pulverised form. It has never been melted yet in larger quantities and the alloy with iron also takes a very high heat. Rich alloys are spongy, the particles not having flowed together,

The general character of tungsten is very much like chromium. It is easily oxidised, but its oxide WO_3 is easily scorified either with basic or acid material.

Though its character speaks against it, tungsten has been tried in the puddle furnace. Addition of wolframite is said to render valuable service; however, as tungsten is readily burnt at a red heat, we rather think it is the scorifying property of wolframite itself that will facilitate the purifying.

There is not the least reason why we should not deny positively the property attributed to wolframite of rendering puddle steel homogeneous. Homo-

geneity and puddling are two contradictory ideas, and cannot possibly go hand in hand, so much the less when a metal is added that makes the charge more refractory.

Another drawback against the use of the wolframite instead of the metal or its alloy with iron, is that all the impurities, such as sulphur, phosphorus, arsenic, &c., likewise pass into the iron.

Tungsten in Pig Iron.

In ferrotungsten made from wolframite the percentage of tungsten never reaches 50 and seldom 40. The wolframite is generally roasted to free it from the greater part of its sulphur and arsenic.

Commercial ferrotungstens contain manganese, but sometimes in such quantities that it seems to have been purposely added, perhaps to lower the melting-point. The wolframite $2FeWo_4 3MnWo_4$ contains about 22 per cent. manganese, whilst Terre Noire ferrotungsten contained 41 per cent. The richness in manganese causes it to be high in carbon, thus e. g. a ferrotungsten from Terre Noire having 24 per cent. tungsten and 41·5 per cent. manganese, contained 5·65 per cent. carbon; whilst one of 29 per cent. tungsten to manganese contained only 1·17 per cent. carbon, which seems to indicate that tungsten itself has no affinity for carbon.

The "Biermann Metall Industrie," which produces tungsten and tungsten compounds as a special manufacture, offers ferrotungsten with 48–52 per cent.

tungsten for about 15*l.* per 100 kg.; 70–75 per cent. tungsten for about 20*l.*; and tungsten, metal, 95–98 per cent. tungsten, for about 24*l.* 10*s.* Evidently it will always be more advantageous to use tungsten metal than its alloy with iron.

Tungsten in Cast Iron.

It is said that 1·5 per cent. tungsten extraordinarily improves cast iron, but very little is known about it. It might be worth while to ex periment upon it, but as yet we cannot say more. We venture to doubt whether 1·5 per cent. tungsten renders cast iron specially adapted for malleable cast iron, recollecting the ease with which tungsten can be oxidised.

Tungsten in Wrought Iron.

It is said also that 2·5 per cent. tungsten makes wrought iron malleable and ductile. Seeing that these are the very properties wrought iron has without any tungsten, this does not say much in favour of its use.

Tungsten in Steel.

Tungsten in steel is appreciated in two respects only, first for its imparting hardness, and, secondly, for its remarkable magnetic properties. Tungsten largely increases the strength of steel; however, as ultimate strength and elastic limit are very near one

another, there is no chance for practical use. A breaking load of 140 kg. may easily be obtained with 7 per cent. tungsten, but then the elastic limit is practically the same. Annealing this hardened steel may give a little more ductility, but 0·75 per cent. elongation is the most. A steel with 2 per cent. tungsten and an ultimate strength of 96 kg. had an elongation of 3 per cent. This want of ductility excludes tungsten steel for most purposes.

The extreme brittleness shows itself also in a bad resistance to impact, hence its unsuitability for solid shot. For tires or rails it is to be rejected at once.

In one class of steel tungsten has proved useful, that is in tool steel. The extreme hardness of tungsten steel may advantageously be made use of. The intensity of hardening is not so great as for chromium, hence where for chromium 1·5–2 per cent. suffices, 2–9 per cent. tungsten must be present to obtain the required result. When 8–9 per cent. tungsten is present the steel is so hard that quenching does not further harden it; hence such steel should be used in the natural state, as it will crack when quenched.

Special tungsten steel tools generally contain 1 per cent. carbon as well, often more. They may advantageously be used for turning chilled iron.

The point of a chilled iron shot being its most important part, any defect however small, say a grain of sand, will spoil the whole projectile, hence they are cast with a head, which instead of being ground off is much more quickly turned off with a tungsten steel tool. The cutting edge of a tool of natural hard

tungsten steel should never be much under 90°. Such steel can only be used in continuous-feed working, as repeated shocks will very soon knock it to pieces.*

Tungsten steel does not stand the fire, and consequently must be forged at a low temperature, between dark and bright red, and not below dark red.

Malleability does not seem to be affected by 2 per cent. tungsten : a 10 mm. square bar could be hammered cold to 5 mm. thickness without showing cracks. Welding tungsten steels is quite out of the question.

Magnetic retentiveness is greatly increased by tungsten. The hardening of magnets of this steel must be done with great care; and their heating best done in a muffle furnace so that they acquire an equal heat all over.

The extraordinarily fine silky texture of tungsten steel is such that, once beheld, it will never be forgotten.

* In the case of a 2-inch square bar of tungsten steel, it being required to know the contents of tungsten, the first question was how to obtain a piece for analysis. Tooling it was simply impossible; but bits were easily obtained by simply hammering on the edges. After these had been taken off, heavier blows became necessary, consequently I took the piece to the smith, asking him to give a few good blows with his sledge hammer. He looked puzzled and, thinking that would be no good, wanted to use his chisel, which of course he knocked to pieces; then, not being allowed to heat the piece, he followed my advice and after a few blows succeeded in delivering me suitable bits for further crushing in the steel mortar. It showed amounts of 6·6 per cent. tungsten and 1 per cent. carbon.

Uses and Occurrence of Tungsten.

Although the use of tungsten as a heating element in the Bessemer or other processes (similarly to silicon) is not excluded, the want of knowledge about the caloric value of tungsten burning to WoO_3 compels us to wait for further information before being able to suggest anything in this direction. At present the chief use of tungsten is as an addition to the ready-made steel in order to impart greater hardness. The brittleness caused by tungsten excludes the steel for most uses.

The "toughness" claimed by Heppe for tungsten steel seems to be negative, and his recommendation of 2·5–5 per cent. tungsten in tires and 0·4–5 per cent. in railway axles of very doubtful benefit. We do not know of the success of his suggestion.

In tool steel the amount of tungsten varies according to purpose ; some analyses are quoted in the table on the next page.

A trial of tungsten steel for armour plates has not succeeded, and for shot, too, it has proved too brittle, and inferior to chromium steel.

Tungsten steel takes a very fine damask. Wootz steel often contains tungsten.

The most suitable quantity of tungsten for permanent magnets is not known to us.

	Tungsten p cent.	Carbon p. cent.	Mangan. p. cent.	Silicon p. cent.
Mushet special steel	7·8	2	0·2	0·1
Imperial tungsten steel	6·4	1·6	2·1	0·2
Crescent „ „	6·7	2·1	2·7	0·1
Böhler „ „	2·5	1		
Seebohm - Dieckstahl tungsten steel	6·6			
Seebohm - Dieckstahl chromium steel	1·5			
Remy tungsten steel	4·0			
Siegen Solingen tungsten steel	0·9			
Sheffield tungsten steel	9·3	0·6	..	0·7
Mushet „ „	8·3	..	1·73	
Howel „ „	2·9	1·15		
Bochum „ „	1·9	1·4	0·4	0·2
? „ „	8·5	0·4	2·5	0·8

ALUMINIUM (Al).

Metallurgical Behaviour.

The reduction of aluminium from its oxide is so difficult that it has only recently been effected by means of the electric arc. Here again simultaneous presence of iron facilitates the reduction, but hitherto no one has succeeded in producing ferro-aluminium in a blast furnace. The manufacture of aluminium and its alloys has developed itself very much, numerous patents have been taken out, and the price of it has been considerably reduced.

According to purity 25–40*s.* per kg. is generally asked, but it is said that by Grabau's patent 1 kg. can be obtained for 10*s.*

Whether the use of pure aluminium will be more profitable than the use of ferroaluminium, is a question of local circumstances, but we think the transport of 90 per cent. of ballast (ferroaluminium generally contains about 10 per cent. aluminium) rather an unnecessary expense, and there being no reason at all why aluminium should be alloyed to iron, the production of ferroaluminium is not likely to have much success, unless it can be manufactured in a blast furnace. When wanted, aluminium can very well be added as such, especially as the impurities in aluminium, though sometimes amounting to 10 per cent. or more, are harmless, considering the smallness of the quantity of aluminium used.

All technically-produced aluminium contains silicon 0·06–4 per cent., and iron seldom under 1 per cent., sometimes as much as 7·5 per cent. The strength of aluminium, 97–99 per cent., containing 0·1–1 per cent. β silicon, 2·8–0·9 α silicon, iron 0·2–0·04 per cent., in its cast state is about 10–12 kg., hammered, 27 kg.

Aluminium is non-volatile, melts at about 700° C., and is distinguished by its very slight affinity for oxygen: it may actually be put into molten nitre without being oxidised.

Aluminium unites readily with iron, chromium, zinc, silver, copper, and other metals, it also easily combines with silicon and boron, so that it even

decomposes molten silicates and borates, and forms aluminates. On the other hand, carbon, nitrogen, phosphorus, and arsenic are without action, whilst the affinity for sulphur is but slight. (Aluminium decomposes AgS, forms AgAl, and leaves the sulphur free).

Even when pure, aluminium does not burn below a very high heat; the presence of silicon makes it easily oxidisable at a red heat. Small quantities of aluminium may eventually be found in pig made from clay-ironstone.

Though aluminium seems to alloy with any amount of iron, alloys of 25, 45, 88 per cent. aluminium are made; still the commercial ferro-aluminiums seldom contain over 10 per cent.

Aluminium in Cast Iron.

Aluminium has a strong tendency to convert α carbon into β carbon, and 0·25 per cent. of it is said to suffice to make even the thinnest part of a casting grey; besides, rapid cooling seems to have the effect of dividing the β carbon very finely, so that the more rapidly the cooling is carried out, the finer grey the iron will be. In this respect aluminium is stronger than silicon, because not only is a much higher percentage of the latter wanted, but so much the more the thinner the casting. Aluminium makes iron softer, more fluid, more easily meltable, and thus gives less shrinkage and

sounder castings. The change in strength caused by some tenths per cent. will be hardly perceptible.

The relatively high price of aluminium, perhaps 20*s.* per kg., would raise the price of one ton cast iron, containing 0·25 per cent. aluminium, by about 40*s.*, which at once excludes its use.

Aluminium in Wrought Iron.

The addition of ferroaluminium in the puddling furnace has been tried, but the benefit was very doubtful, as might be expected. No difference in puddling was observed, and the bar iron containing 0·25 per cent. aluminium showed superior strength, though, as no complete analysis is given, no conclusion can be drawn from this one experiment. The iron was found to be harder. We fail to see any advantage in adding aluminium to a puddle charge.

Aluminium in Steel.

The most important property of aluminium is its lowering the melting-point of steel considerably; as yet this seems to be the only advantage of it, and even this is not made use of, on account of the high price of aluminium.

The discovery of Wittenström, that addition of 0·05–0·1 per cent. aluminium renders wrought iron fusible at a good heat, and even capable of being cast, is very interesting, but of less use than at first was anticipated. Since the difficulty of making good soft steel castings is now pretty well overcome,

why should one submit to the trouble and expense of melting bar iron in crucibles, adding a costly metal, and after all to obtain nothing particularly good? Obviously it is visionary to think that molten and cast bar iron should possess the combined properties of bar iron and steel. Cast wrought iron is no longer "wrought" iron, having lost its fibre. (To speak scientifically, the cells are no longer elongated cells, separated by slag, but round ones separated by cement).

In the Mitis Foundry of Stockholm it is said that bar iron is melted and after fusion aluminium is added so as to impart enough fluidity for casting. This foundry possesses two petroleum residue furnaces, each containing six crucibles of about 40 kg. charge. Seeing that the Mitis steel does not possess any superior property over ordinary good mild steel, the Mitis process is of doubtful advantage.

Of more advantage would be the addition of aluminium in the ladle, so as to obtain sound castings, since aluminium makes the steel very liquid and by lowering the melting-point produces an overheated metal that, when given time to cool down, has opportunity to get rid of its gases and will give sound castings.

The said non-affinity for oxygen, or at most very small affinity, makes it very improbable that aluminium would act like silicon and decompose oxides; besides, even if it did, its oxide Al_2O_3 being difficult to scorify would interpose between the molecules and interfere with soundness.

The above mentioned influence of aluminium on the melting-point, stated to be lowered some 250° C., is contradicted by Hadfield and many others.

The effect of 0·05–0·1 per cent. aluminium on the mechanical properties is undefined; some claim a rise of 50 per cent. in the strength, others think such a quantity of no perceptible influence. Hadfield found aluminium scarcely to increase tenacity and elasticity, nor was the ductility lessened by 0·75 per cent. He found the hardness not to be increased even with 7·8 per cent. aluminium. The malleability of steel is annihilated at 5–6 per cent. aluminium.

Hadfield noticed a great heat to be developed when aluminium was added to steel, and thinks a chemical combination of aluminium and iron to be the cause. When a careful observer like Hadfield doubts the overheating of steel when aluminium is added to it, we rather feel inclined to doubt likewise.

It is said that aluminium steel takes a fine damask. Faraday found 0·01–0·07 per cent. in some Indian Wootz steel, whilst others did not find any.*

Use and Occurrence of Aluminium.

The use of aluminium in iron and steel making will remain what it is, i. e. practically none at all, unless its price becomes reduced to at most a tenth of what

* We might mention that the determination of very small quantities of aluminium in iron belongs to the most tiresome problems of analytical chemistry, and negative results are of no value.

it is at present, or unless some remarkable property is discovered. Though more than one has tried to introduce aluminium for the manufacture of steel without blow-holes, we doubt whether any one will have success with it.

Neither does aluminium decompose iron oxides, nor does Al_2O_3 form easily fusible compounds with iron-manganese, or silicon oxide.

If it be true that 0·1 per cent. aluminium lowers the melting-point some 250° C., this would be a very useful property in dealing with chromium steels, tungsten steels, &c., but if this is not true we do not see any use for aluminium.

NICKEL (Ni).

Metallurgical Behaviour.

The reduction of nickel oxide to nickel is extremely easy, but unfortunately nickel seldom occurs as oxide and even then those ores are low in nickel. The nickel ore of New Caledonia is chiefly nickel oxide, and the percentage of nickel seldom reaches 7 per cent., though it may occasionally run up to 20 per cent. These ores are free from arsenic and sulphur and contain about 5 per cent. iron. More commonly nickel occurs as arsenide, sulphide, or both, i. e. as NiAs, NiS, or NiAsS. The first may contain 44 per cent. nickel.

The metallurgy of nickel is pretty complicated, and in broad outlines is a repeated roasting and smelting down with silicious matter in a shaft furnace, then an oxidising melting in a reverberatory furnace (or Bessemer converter), finally a reducing smelting. In this way nickel can be obtained tolerably pure, say 98 per cent. By treatment in a small blast furnace (8 metres high) a ferronickel can be obtained.

Nickel unites with 9–9·5 per cent. carbon and 6–6·2 per cent. silicon, and this must be taken into consideration when smelting ferronickel.

The chemical character of nickel is very much like that of copper, i. e. easy to reduce, difficult to oxidise. Its oxide can be reduced at a red heat and a nickel bar can be forged red-hot without scaling. These two properties at once tell the behaviour of nickel in different processes.

When coming into use the manufacture of ferronickel will be more economical than that of pure nickel metal, because iron is the latest companion of nickel, that is to say, arsenic, bismuth, sulphur, &c., are all eliminated before the iron. But, whatever the process, the comparative rareness of its ore will ever cause nickel to be an expensive addition.

Nickel in Pig Iron.

Though nickel and iron alloy easily in any proportion there is no great variety in ferronickels, and very little is known about nickel in pig or cast iron. It raises the melting-point of iron, but as ferronickel

will very likely be high in carbon, the affinity of nickel for carbon being known, it may be that nickel and carbon neutralise each other in this respect. Nickel contains carbon as α carbon and β carbon depending on the conditions of cooling; thus nickel with 1·33 per cent. carbon showed when cooled slowly 0·32 per cent. α carbon, when cooled rapidly 0·6 per cent. α carbon.

An attempt to improve cast iron for guns by adding 2·5 per cent. nickel has given the opposite result, i.e. a loss in strength; but unless complete analyses are given, such statements are of no use.

Longmaid took out a patent for 0·01 per cent. nickel in wrought iron, which was to improve the iron greatly; however, nobody doubts the valuelessness of such homœopathic additions.

The specific gravity of nickel is high 8·9–9 and the nickel alloys show an increase in density.

Nickel in Steel.

If it were not for the information Riley has given on nickel in steel our knowledge in that regard would be but small. According to Riley's experiments nickel imparts to steel a higher tensile strength and elastic limit without diminishing the ductility correspondingly.

As in the series of Riley's experiments the variations in the carbon and manganese are very great, a graphic curve cannot be constructed on those

figures, but it is of great interest to compare steels of nearly equal carbon and manganese free from nickel and with nickel.

Analysis.			Strength.		
Ni per cent.	C per cent.	Mn per cent.	Ultimate Strength. kg.	Elastic Limit. kg.	Elongation per cent.
0	0·40	0·70	54	32	21
1	0·42	0·58	87	47	19
5	0·50	0·34	73	51	14
49	0·35	0·57	58	32	20

Another:

0	0·22	0·23	47	25	23
4·7	0·22	0·23	64	45	20
0·5	0·30	0·30	67	44	15

and for further comparison,

0·2	0·30	0·78	57	37	22

From these few examples it may be seen that the gain in strength is remarkable, and the loss in ductility only slight.

Nickel steel shows homogeneity, it does not yield locally, hence a low contraction figure, but a high elongation. A 25 per cent. nickel test-piece gave an

ultimate strength of 66 kg., an elastic limit of 24 kg. elongation 40 per cent., this being uniform throughout the whole piece. However, such rich steels are not likely to come into use, because of their high price; thus it would be of value to know more about the lower nickel steels.

Nickel increases hardness considerably: test-pieces of 2, 5, and 10 per cent. nickel, with respectively 0·7, 0·85, 0·5 per cent. carbon, were too hard to be tooled with Mushet steel. As to taking temper, Riley leaves us in the dark, but states that about 150 kg. ultimate strength is combined to 85 kg. elastic limit and 9 per cent. elongation (in 100 mm.). Evidently, as regards the elastic limit, the effect of hardening is unlike that on other steels. We have seen that steels high in carbon, chromium, or tungsten, when hardened, show practically no elongation, and little difference between ultimate strength and elastic limit.

Resistance to shock and compression have still to be ascertained: the torsional tests, determined by the number of twists, give not the least insight. It would be of greater use to be able to compare the number of degrees of torsion in a given unit of length, at a given weight and leverage, of nickel steels and other steels. As in the case of tensile strength, here it is of more importance to know the elastic torsion than the ultimate number of twists that produces rupture. Nickel does not interfere with the working qualities, which might be expected, considering the ductility of nickel and its

great resemblance to iron.* Nickel steel rolls and hammers well, and punching can be done without fear of cracking. Machining takes more work, but can be done with ease upon the lower nickel steels.

Nickel steel stands the fire well, only a 25 per cent. nickel steel has to be heated with more care. Welding is possible up to 1 per cent. nickel, above that amount it becomes more difficult. Nickel raises the melting-point, but Riley found no difficulty, and affirms nickel steel to be more fluid and thinner than ordinary steel. He gives no information about the melting-point, but his mentioning that the steel pipes more, seems to be in accordance with a higher melting-point.

Riley also drew attention to the fact that nickel steel can be melted in an open hearth without fear either of burning or of slagging of the nickel, and that all scrap can be used continually, that is to say there is no nickel lost. These statements fully confirm what we remarked in the earlier part of this chapter upon the chemical character of nickel.

Nickel steel lies dead in the mould, and the homogeneity caused by rapid cooling and setting and absence of liquation is fully proved by the test pieces not yielding locally.

A very, if not the most, important property of nickel is that it diminishes corrosion, the richer

* Though, as is well known, the properties of alloys cannot be deduced from the properties of their components, yet in iron alloys we often encounter the same properties as are possessed by the metals they are alloyed with. We instance chromium steel and tungsten steel.

alloys (25 per cent.) being practically non-corrodible, though 5 per cent. nickel samples showed no great difference.

The statement of Hadfield regarding the non-magnetism of a nickel-iron-manganese alloy is strange, especially as nickel itself is one of the few metals that take up magnetism.

Uses and Occurrence of Nickel.

The use of nickel or ferronickel will be exclusively as addition to the ready made steel. The high price of nickel is a serious objection to its use, and as articles of cast iron cannot bear increase in price without risk of being superseded by steel, nickel will not be added to cast iron unless some very remarkable property be discovered for it. So long as the character of nickel steel remains to some extent unknown, a wide application of it is not to be expected, and even were it better known its price would put a bar between its aptitude and its employment. Taking the price of nickel as about 5*s.* the kg., this involves an increase in the price of a ton of 5 per cent. nickel steel of about 12*l.*; or taking the price of one ton of good open hearth steel as about 12*l.*, the addition of 5 per cent. nickel means a rise in price of 100 per cent.; even 1 per cent. nickel causes a rise of 20 per cent. in price. With these or similar figures before us we may doubt whether building engineers will take to it. Possibly an increased use of nickel might cause a fall in its price, but the very limited resources of nickel ores will keep the price up.

In some special cases the higher price of nickel steel might be counterbalanced by such advantages as increased strength, reduced scantlings, or less corrosion. The use of it for boiler plates is the first that occurs, and for shipbuilding, especially torpedo boats, &c. Of greater promise, perhaps, is its use as ordnance material, because, *if* good, a high price is no obstacle, every nation striving to have the very best material obtainable; but most certainly, before nickel steels can hope to be used for artillery, their true nature will have to be thoroughly ascertained.

A metal possessing an ordinary ductility but 45 kg. elastic limit instead of 30 kg., and not too hard to machine, will be welcome. Either reduction of weight in field or mountain guns, or increase in strength for heavy guns, involving either a larger margin of safety or increased ballistic power per ton of gun, will be a welcome circumstance.

Two more things are a *conditio sine qua non* for gun-metal, i.e. it must stand a sudden stress as well as one slowly applied (as in a test piece) and it must stand initial internal strain (a negative tension). For armour plates nickel steel will prove good in that it imparts hardness and strength. Kitson stated an instance of a French armour plate, containing 5 per cent. nickel, having 142 kg. ultimate strength and 8 per cent. elongation, hence, though strong, it was not brittle. Recently nickel steel has again been tried for armour plates and has done very well.

Though in comparison to a steel plate manufac-

tured also by the Le Creusot works, their nickel steel plate containing 4 per cent. nickel undoubtedly was the better, no conclusion can be drawn from this trial (Annapolis, 1890). It may be repeated here that the compound plate was evidently a failure altogether. Schneider's solid steel plate yielded locally for the first four rounds, which indicates a steel of great homogeneity, not brittle, and free from internal strains. The fifth round (in the cutting point of the diagonals of the rectangle formed by the former four rounds) caused a crosswise crack in the ordinary steel plate and did not give rise to cracks in the nickel steel plate. This indicates a superiority in quality of the latter, but whether this superiority is solely due to the percentage of nickel, whether such a plate can be current manufacture, whether the great expense of the nickel will be justified by the better quality—these and many other questions remain to be settled before enthusiasm can be expected of anybody not directly interested in the affair. The act of the American Government in asking a credit of 1,000,000 dollars for the purchase of nickel ore seems rather a hasty one.

Recent investigations into the behaviour of nickel steel at low temperatures indicate its decrease in resistance to shocks. This, however, is no reason for condemning nickel steel, seeing that all steel (except Hadfield's manganese steel) possesses the same disagreeable property.

COBALT (Co).

The metallurgical behaviour of cobalt is quite similar to that of nickel, it being easily reduced, but oxidised with difficulty.

The quantities of cobalt present in some ores is too little to give more than slight traces in the pig, and cobalt ores are too dear to be used purposely.

Iron and cobalt unite easily. Buttons of 53 and 13 per cent. cobalt proved to be well molten, but not malleable. Alloys of cobalt with iron are said to be strongly magnetic.

The price of cobalt being about ten times that of nickel, there will be hardly reason for experimenting with it, since an influence on steel different from that of nickel cannot be expected.

ARSENIC (As).

Metallurgical Behaviour.

Many ores contain some arsenic, at times to the extent of a few tenths of a per cent., and generally in the form of a sulphide, though probably often as arsenide of iron. Arsenide of iron has a great affinity for iron and seems to alloy with it in any proportion.

Arsenic being very easily volatilised (at about 450° C.), it was always thought that in the blast furnace it would all disappear, but Pattinson and Stead have proved that this is by no means the case. On the contrary, practically all arsenic contained in the burden passes into the iron. This fact was established, first, by direct experiment, the estimated arsenic always corresponding to that actually obtained; secondly, by the absence of arsenic in the dust deposited in the flues of blast furnaces. Consequently a good many pigs contain arsenic, but fortunately the quantities are not very large. Considering the great ease with which arsenic is oxidised it seems strange that it cannot be eliminated by any oxidising process, not even in a basic lined vessel.

Addition of lime in the blast furnace will prevent arsenic from being volatilised, and, unfortunately, cause it to pass into the iron.

Arsenic in Pig Iron.

Fortunately the quantities of arsenic in the ore, and thus eventually in the pig, are not very great, nevertheless the percentage of arsenic in pig iron is much higher than has ever been suspected.

Stead gives instances of pigs containing arsenic, and found in Bessemer pig made from Spanish ore 0–0·05 per cent.; Cumberland, 0·02–0·04; Cleveland, 0·01–0·03; Cleveland basic pig, 0·02–0·03; Lincolnshire, 0·10; Leicestershire, 0·12; ferro-

manganese, 0·01–0·15. Seeing that 0·04 per cent. arsenic never interfered with the high quality of Cumberland pig, that amount may for certain be considered harmless, and probably a higher percentage would not deteriorate the pig; perhaps even 0·2 per cent. may be looked upon as allowable, though, for safety's sake, less is preferable.

Arsenic in Cast Iron.

Very little is known upon this subject. Arsenic seems to give fluidity and to lower the melting-point. Possibly arsenic, like sulphur, lowers the limit of saturation of iron for carbon, and has a tendency to keep the carbon in the combined state so that it renders the iron harder. The increase of *a* carbon by increase of arsenic is in accordance with Blair's communication of a German pig containing

1·01 per cent. As.;		0·96 per cent. *a* C.	
1·29	„	1·55	„
1·70	„	1·93	„

Arsenic in Wrought Iron.

Arsenic seriously interfering with the property of welding, will be objectionable in any welding process. Professor Åkerman states 0·05 per cent. to be injurious to welding.

Arsenic in Steel.

Harbord and Tucker made a series of experiments to investigate the influence of arsenic on steel and found 0·17 per cent. arsenic in steel, containing 0·12 per cent. carbon and 0·35 manganese, not to alter the bending properties.

Some few tenths of a per cent. arsenic cause a rise in the ultimate strength, but a fall is soon reached, and above 0·66 per cent. the ductility is decreased in a very marked way. The working properties are influenced by about 0·1 per cent., though samples with 1·18 per cent. are recorded as rolling fairly.

Welding was good at 0·07 per cent. arsenic, fair at 0·17, poor at 0·20, impossible at or above 0·35. Quenching notably hardened the metal. A curious fact is that arsenic added to casehardening matter gives a very hard steel. When iron is heated in it a hard skin of iron arsenide is formed which, according to Ekman, is non-corrosible; according to Percy, without influence on the rusting properties.

Uses and Occurrence of Arsenic.

Arsenic imparting nothing but bad properties is a real deteriorating element and very unwelcome. Except perhaps for chilled cast iron and casehardened steel it is considered useless and objectionable. Its occurrence in steel will be as frequent as in steel-making pig, but as it is seldom or never sought for no analyses are forthcoming.

ANTIMONY (Sb).

Antimony is perhaps found as frequently as arsenic, but no analyses are published.

Antimony and iron alloy readily, the alloys are hard and brittle. Most likely antimony behaves exactly like arsenic, but no information is to be had on the point, and there is not much interest in it. According to Karsten 0·11 per cent. antimony renders bar iron coldshort, but the presence of 0·38 per cent. phosphorus in his sample makes his statement valueless. His observation that 1 per cent. antimony pig treated in the low hearth gave white fumes and that the iron contained 0·23 per cent. antimony and was red and coldshort, is of little practical value.

ZINC (Zn).

Zinc very often occurs in iron ores and is easily reduced; however, it is easily volatile, and has no great affinity for iron, thus the quantities of zinc taken up by the iron in the blast furnace are small or none. The greater part of the zinc is found in the furnace-dust that gathers at the throat and in the flues in the form of zinc oxide.

Though zinc may be considered not to occur in iron, it is a fact that when zinc is added to grey iron the latter becomes hard and rather inclined to chilling.

Zinc forming alloys with silicon the explanation

for the above-mentioned phenomena is at hand, it being known that loss in silicon means increase in *a* carbon.

Zinc being of no further importance we may pass on to our next element.

LEAD (Pb).

Lead is of as little importance as zinc; it hardly alloys with iron.

Some ores contain lead, notably those from Oberschlesien, from traces to 2 per cent. Lead not alloying with iron, and being much heavier, separates easily from the pig and gathers at the bottom.*

There are blast furnaces that obtain 25 tons of lead monthly; as this lead contains silver (500 grains per ton), and the silver contains gold, the presence of lead in the ore is not unwelcome and nowadays is even paid for.

TIN (Sn).

Tin and iron combine readily, but fortunately the occurrence of tin in iron ore is exceptional or the amount is so small that it is harmless.

* The lead often eats a way right through the foundation and large quantities of lead thus accumulate at unsuspected places.

Tin is said to cause hardness, brittleness, red-shortness in steel, and in cast iron it decreases the quality, so that of however great importance tin may be for tinplating it is of none as regards alloying with iron.

SILVER (Ag).

If it were not that the name "silver-steel" is met with now and then we should not mention it. The quantities of silver which it is possible to introduce into steel are very minute. Longmaid again had the addition of 0·0025–0·005 per cent. silver to steel patented, but it is doubtful whether any one else believed in such homœopathic doses.

Alloys of iron with other precious metals are of little importance, for well-known reasons of cost. Gold (Au) alloys easily with iron and so does platina (Pt). Iron containing 0·25 per cent. platina dissolves with extraordinary quickness in acids—a property which might be made use of in some special cases.

We need not wonder that Longmaid took out a patent for the addition of 0·007-0·014 per cent. gold, or platinum, or both.

Of the alloy with *Osmium-Iridium* may be mentioned that it is said to be capable of being hardened without containing carbon. We cannot say whether this property also has been investigated in recent years.

MOLYBDENUM (Mo).

Molybdenum is occasionally present in iron ore (Swedish ores); it has a particular affinity for silica and alumina, hence the whole of it will be found in the cinder. Impure alloys of molybdenum and iron have shown great resemblance to tungsten steels, but the pure metal being very costly there is little hope of its application.

VANADIUM (Va).

Vanadium in small quantities occurs in many iron ores; like molybdenum, it has a particular affinity for silica and consequently will appear in the cinder.

The Le Creusot works might yearly produce some 60 tons of vanadic acid from their blast furnace slags. Traces of vanadium are sometimes found in iron, and some pigs from Wiltshire are found by Riley to contain 0·68 per cent.

POTASSIUM (K); SODIUM (Na).

Both these metals will not improbably play a more important part in iron metallurgy than they have hitherto done. Both can very likely be found in charcoal pig. They are easily reduced and very easily

oxidised, so that in any oxidising process they will at once disappear.

Not improbably sodium will come into use as a deoxidising agent in steel-making; it is the cheapest element for this purpose, and its oxide combining with any other oxide is thus easily expelled.

Rich alloys of iron and sodium do not seem to have been made as yet; addition of sodium in the metallic state might present serious difficulties, but it is said that experiments in this direction are being carried on, and certainly the nature of sodium suggests success.

An alloy of iron with 25 per cent. potassium has been made, but potassium is much dearer than sodium.

BARIUM (Ba); STRONTIUM (Sr); CALCIUM (Ca).

Neither barium nor strontium seem to alloy with iron. Though the presence of their salts might have some influence on the cinder, this point is very little investigated.

Carbonates of barium and strontium raise the melting-point of the slag, and both being dearer than calcium carbonate and inferior to it we fail to see the advantage of taking to them.

Only recently attention has been drawn to the presence of calcium in iron and steel, and though its oxide, lime, is not reducible by carbon there may

be circumstances under which the reduction and alloying take place. Mathesius found a basic steel to contain 0·28 per cent. calcium, which quantity, however, does not seem to have had any influence. Knowing the great facility with which calcium burns we should think it a very unwelcome element in steel. A Clarence pig contained 0·4 per cent. calcium and after remelting 0·8 per cent.

MAGNESIUM (Mg).

Magnesium is said not to alloy with iron, or at all events in very minute quantities only, such as 0·03–0·06 per cent. (Clarence). The asserted beneficial effect of magnesium on a steel bath can only be on account of its great affinity for oxygen; but the resulting oxide of magnesium being highly refractory and difficult to slag, we do not think much of it.

GASES.

The great importance of gases in iron and steel, though ignored by some people, is acknowledged by most steel-founders.

The deteriorating effect of gases has its cause in two facts: first, that fluid iron or steel is capable of occluding a great deal more gas than when solid, and

as a result thereof molecules of gas are present side by side with molecules of iron, i. e. on solidification of the mass the gas is divided intermolecularly; and secondly, that the excess of gas, i.e. the non-occluded gas, has some difficulty in passing through a comparatively thick fluid, and this is so much the more so the less fluid the metal is, hence there will come a moment at which escaping gases can no longer pass through and have to remain in the metal, forming bubbles or honeycombs. The origin of these gases may either be the result of reactions in the solidifying mass, e. g. iron oxide plus carbon gives carbonic oxide (CO) and carbonic acid (CO_2),* or it may be the remains of atmospheric air, chiefly nitrogen (N) and hydrogen (H).

The worst of it is that these different causes for gases in solid iron or steel are more or less independent of one another, and thus complicate the effect and greatly add to the difficulty of a scientific explanation of observed facts. The questions of solid castings is a very serious one and a careful study of the matter is needed. For a better understanding we shall divide the subject into three parts, viz.:—

A. Intermolecular gases;
B. Reactionary gases;
C. Mixed gases.

* Between the great variety of elements in iron and steel a good many reactions giving gaseous products are possible; even hydrogen and nitrogen may be such; however, carbonic oxide and to a less extent carbonic acid are the principal and most common.

A. Intermolecular Gases.

It has long been known that iron is capable of taking up gases, notably hydrogen and nitrogen, but whether the union is a true chemical combination or a physical one is, at all events for hydrogen, difficult to settle. Probably a combination Fe_nH_n does not exist, and very likely a combination Fe_2N does exist.*

Any iron or steel gives gas when heated in a vacuum, the gas generally being hydrogen or nitrogen, or both. This fact pitilessly annihilated Fremy's theory that nitrogen was essential to steel—in other words, that steel was steel because of the nitrogen, and would not be steel without it.

Nitrogen is found in thin iron wire, 0·0123 per cent.; iron armour plate, 0·0131; open hearth steel (0·22 carbon), 0·0107; crucible steel (1·30 carbon), 0·0172; spiegel-iron (3·8 carbon, 20 manganese), 0·0041; or from 32 to 137 cubic centimetres per kg. iron.

Hydrogen may be found in still larger quantities,

* Passing a current of dry NH_3 over dry $FeCl_2$ gives absorption of the first; heating this mixture in NH_3 gives under favourable circumstances a grey powder of the formula Fe_2N. On dissolving this Fe_2N in hydrochloric acid it gives an ammonium salt, which may be looked upon as a fair proof that the nitrogen was not physically but chemically combined. Fe_2N may also be obtained when passing a current of NH_3 over reduced iron; its temperature of combination is only slightly under the temperature of decomposition.

e. g. in ferromanganese, 0·0028; ferrosilicon, 0·0028; open hearth steel, 0·0017; or, calculated on volume, the first two contained a volume of hydrogen nearly equal to 2·5 times the volume of the iron, the open hearth steel 1·5 times its volume.*

Troost and Hautefeuille made some very interesting experiments regarding occluded gases. Heating 500 grams respectively of charcoal, cast iron, spiegel-iron, and forged crucible steel for 190 hours at 800° C. in vacuo, they found these to contain:—

	Spiegel-iron. ccm.	Cast Iron. ccm.	Steel. ccm.
Hydrogen	27·0	12·3	0·50
Nitrogen	2·5	1·0	0·25
Carbonic oxide ..	0·0	2·8	1·46
Carbonic acid ..	0·0	0·6	0·05
	29·5	16·7	2·20

They also heated the same samples in a current of hydrogen, and after subsequent heating in vacuo found an absorption of

	Cast Iron. ccm.	Steel. ccm.
Hydrogen	44·0	6·4
Nitrogen	1·5	0·5
Carbonic oxide	1·1	0·9

* Many other metals, notably palladium, platina, nickel, copper, aluminium, potassium, sodium, gold, silver, and others, have the property of occluding hydrogen; thus palladium is capable of absorbing 935 times its volume of hydrogen (that is, 1 ccm. absorbs nearly 1 litre of hydrogen; platina about 5 times; nickel about 165 times; silver about 1; iron about 20 times, and so on.

After similar heating in carbonic oxide:—

	Cast Iron. ccm.	Steel. ccm.
Hydrogen	1·5	0·8
Nitrogen	0·7	0·4
Carbonic oxide	14·7	2

Calculated on percentages of volume we get

	After heating in	
	Hydrogen.	Carbonic oxide.
Cast iron, originally 25 p. c. gas ..	72 p. c. gas.	26 p. c. gas.
Steel „ 3·4 „ „ ..	12 „ „	6 „ „

When chemically combined the amount of gases has to be expressed in percentages of weight, and these being so very low there is no wonder that they do not show any influence.

When physically combined (occluded) the amount must be expressed in percentages of volume, and though these are sometimes considerable the gases do not seem to have any notable influence beyond a lowering of the specific gravity.

Wedding considers hydrogen to have as little importance as nitrogen—a gas which, so much thought of by Fremy, is hardly taken into consideration at the present time. The cleansing of iron or steel from scale by dipping it into acid, as practised in wire-making, causes the metal to take up hydrogen and become brittle; the brittleness, however, can be removed by annealing or long rest.

B. Reaction Gases.

These are of quite a different character, being for the greater part neither chemically nor physically combined, and thus cause discontinuity of mass—that is, generally speaking, loss in strength.

When steel is being made from an iron bath by oxidisation, i. e. burning away the greater part of the silicon, carbon, manganese (and eventually phosphorus), a point will be arrived at where the iron itself commences to burn, although more easily oxidisable elements are still present. It is a law in chemistry that the dilution of liquids is a function of the speed wherewith reactions take place between them, and the same may be observed in steel-making.

At the finish of the process, when the greater part of the carbon has been burnt, the solution of carbon in the fluid iron is so diluted that reaction between carbon and oxygen takes place much more slowly; the consequence is that the iron gets oxidised too, and is overblown low carbon steel. A few tenths of a per cent. of oxygen may be present in the bath together with carbon (probably in the form of protoxide, FeO). When the metal is tapped it may, according to circumstances, either lie dead in the mould or boil over it. In both cases, on cooling and solidification, some reaction will go on; but then the resulting gas can no longer pass through, and gathers in smaller or bigger bubbles. Compression during solidification causes the bubbles

not to move, and thus to remain very small,* and in this way to resemble more or less the occluded gas in regard to their influence on the properties of the steel. At all events microscopic bubbles most certainly do a great deal less harm than large ones, though an essential difference is that reaction gas, being chiefly carbonic oxide, is present as molecules, whereas occluded or combined hydrogen or nitrogen are probably present as atoms; and in the case of hydrogen there is nothing strange in looking upon the element as a metal of very low volatilising point (Graham), but solid when combined with iron. (Formulæ for the alloys of hydrogen and metals above alluded to are Pd_2H, Na_2H, K_2H.)

It is obvious that the reaction which takes place after tapping between carbon and oxygen may be suppressed by adding silicon to the metal, that element acting much more quickly than carbon; and the product of oxidation is not a gas, but a solid, easily scorified.

The softer the steel, i. e. the less carbon present, the more trouble is caused by reaction gas. The medium steels do not invariably emit gas. Steel

* That compression cannot possibly press out the gas, but on the contrary must, so to say, press it in, is so evident a fact, based upon well-known physical law, that it needs no further explanation here. The observed and misleading fact that during compression burning gas comes out of the mould is a different thing altogether; that is because, at a certain pressure, only a certain amount of gas is absorbed by a liquid; the excess must come out, but it is not at all *pressed* out. We instance the analogy of soda water: would anybody ever think of *pressing* the carbonic acid out of it?

free from blow-holes can be cast without the special addition of either silicon or manganese, but as a rule this is not the case.

The beneficial effect of aluminium is probably to be attributed to its imparting thin fluidity. Aluminium is not a metal apt to oxidise, and whether it is capable of decomposing iron oxide remains to be proved, and is very doubtful; thus it does not interfere with the reactions, but by making the metal thinly fluid gives ample opportunity for escape of gas.

Magnesium oxidises readily and it is not at all impossible that it will decompose iron oxide, thus leaving no oxygen for the carbon, in other words, suppressing reaction between those two elements.

C. Mixed Gases.

In the manufacture of iron and steel immense quantities of air are consumed. Now all this air contains water, which water has plenty of opportunity to be decomposed into hydrogen and oxygen, for there is a very high temperature in the blast furnace—far above the dissociation temperature of water—there is glowing carbon which at once decomposes H_2O, there is hot iron which also decomposes it. Starting from these premises, and knowing the capacity of iron for absorbing hydrogen, it is not surprising that all technically prepared iron contains hydrogen. From the blast furnace the steel pig goes to the cupola (generally), where a

new chance is offered of taking up hydrogen; it is then converted into steel, say in a Bessemer converter, where again it comes into close contact with air, and so with water. Steel so made contains large quantities of hydrogen. Now fluid steel can contain a good deal more gas than solid steel can, or, when the steel is solidifying, the gas, now chiefly hydrogen, will escape from it, just as when water freezes the air escapes from it—often, when the whole of the air cannot escape, causing the ice to become spongy.

With steel, in like manner, the escaping gas passes through the metal, but this being not thinly liquid, like water, it rises and sputters, giving the aspect of boiling. We see this hydrogen and the before mentioned carbonic oxide do the like, but the cause is different.

The hotter the metal the more gas it is capable of containing,* or the more spongy the ingot will be, hence the preference given to casting cold. For a given carbon point there is a given temperature most suited for casting, and Stead even considers the whole question of blow-holes entirely dependent on the temperature of casting.

Bessemer steel is generally found to contain most gas, due to the much higher temperature of casting,

* Odelstierna says, the hotter the bath (open hearth) the less gas will be taken up, because more silicon is left in the metal. On a close comparison, this assersion and ours above are not contradictory. We say, the hotter the metal the more gas taken up, if it has a chance for so doing, as in the Bessemer process. The open hearth steel has no such chance, and has only to put up with reaction

the forcing of air *through* it, and want of time to get rid of the gas. Open hearth steel, on the other hand, contains less gas, because of the lower temperature and the long time of liquidity under cover of slag, which means no opportunity to absorb gas and plenty of chance to let it loose, hence open hearth steel is better suited for solid castings. Crucible steel contains least of all, because of the attention paid to its killing, i. e. the elimination of gas and taking up of silicon.

It will be of interest to quote some of Dr. Müller's experiments on gases in iron and steel.* The total quantity of gas found greatly depends on the fineness of the particles into which the sample is divided, and absolute correctness can never be attained so long as it is not possible to divide the iron into atoms (respectively molecules of carbide, &c.). Dr. Müller found in—

	Total Gas p. c.	H p. c.	N p. c.	CO p. c.
Mild steel (basic), final addition FeMn†	36	85	14·3	0·6
Basic steel, no final addition ..	20	64·5	35·4	0·6
„ „ final addition FeSi and FeMn	22	86·4	12·7	0·4
„ „ final addition FeSi	6	54·7	45·3	0·0

* The objection to Dr. Müller drilling his samples under water is proved to be quite unfounded by his comparative experiments, using oil or mercury instead of water. Besides, the idea that water would be decomposed when drilling a piece of steel in it is rather a funny one, and can hardly be entertained by any chemist.

† FeMn means ferromanganese; FeSi ferrosilicon.

Gas samples from Bessemer ingots:—

	H p. c.	N p. c.	CO p. c.	CO_2 p. c.
Rail steel ingot not honeycombed	47·3	7·9	37·3	7·5
Spring steel ingot not honeycombed	49·5	8·6	34	7·9
Rail steel ingot slightly rising	51	2·2	38·4	8·4
„ „ „ rather rising	39	21·6	31·5	7·7
„ „ „ boiling	20·7	6·5	70·7	2·1
Bessemer steel ready blown ..	54·2	24·9	18·6	2·2
Open hearth steel	35·1	35·1	48	1·5
Basic Bessemer steel..	5	30	65	

With the exception of basic steel, open hearth and Bessemer steel give on solidification more hydrogen than carbonic oxide, the carbonic oxide being the result of a reaction and the hydrogen driven out simultaneously. The moment at which the gases are taken greatly influences their composition. Stead analysed a number of steels and found the gas to be for the greater part hydrogen, as shown below:—

	H p. c.	N p. c.	CO p. c.
Bessemer rail steel	90·3	9·7	0·0
„ spring steel	81·9	18·1	0·0
„ rail steel before spiegel addition	88·8	10·5	0·7
Bessemer rail steel after spiegel addition	77·0	23·0	0·0
Solid steel	92·4	5·9	1·4
„ „ forged	73·4	25·3	1·3
Open hearth steel	67·0	30·8	2·2

We may mention that puddle iron contains large

quantities of gas and chiefly carbonic oxide, so for example a sample containing nearly five times its volume of gas showed CO 44 per cent., H 24·5, N 31·5.

It is interesting to compare the composition of the gas found in a big bubble in a plate of puddle iron and in a similar swelling in a basic steel beam :—

	CO.	CO_2	H.	N.
The first was, per cent.	70·5	21		
The second was „	27	1·6	43	28·5

The gas found in the closed Mannesmann tubes being for 99 per cent. hydrogen is considered by Dr. Müller a striking proof of his theory that it is chiefly hydrogen that causes blow-holes in steel.

In conclusion, it may be said that the great importance of gases in iron and steel is not on account of the particular influence of gases, but because they involve loss of continuity, hence gases are among the greatest enemies of the foundry.

When the metal has to undergo subsequent treatment under the rolls or hammer some prefer an ingot that is not wholly sound, the ingot bearing stronger compression from one pass to the other. Obviously the honeycombing must not be of such a character as to prevent welding, in other words, the blow-holes or pores must not have had communication with the air, must not be the result of a strong contraction on cooling (piping).

Some complete analyses of irons and steels, which may be found useful, will bring this work to a close.

ANALYSES OF VARIOUS

FOUNDRY

Name of Pig.	Combined Carbon, α C.	Graphitic Carbon, β C.	Total Carbon.	Manganese.
Coltness No. I.	0·20	3·30	3·50	1·56
Bowling No. I.	..	..	2·99	..
Grasebrook's No. I.	..	3·07	..	0·96
Hematite No. 1.	0·10	3·80	..	0·40
Langloan No. I.	0·46	3·40	3·86	1·62
Clarence No. I.	0·13	3·39	3·52	0·68
Phœnix No. I.	0·49	3·16	3·65	0·97
Gutehoffnungshütte No. I. ..	0·26	3·28	3·54	0·18
Hoerde No. I.	0·21	3·34	3·45	1·13
Terre Noire No. I.	0·94	3·25	4·19	1·25
Viscaya No. I.	..	..	..	1·00
Cleveland No. I.	..	..	3·75	0·30
W. Rdiing of Yorkshire No. I.	0·58	3·42	4·00	3·60
Langloan No. II.	..	..	3·22	1·21
Hematite No. II.	0·25	3·78	4·04	0·35
Hoerde No. II.	0·12	3·21	3·33	1·17
Terre Noire No. II.	1·23	2·55	3·58	1·05
Viscaya No. II.	..	..	..	1·00
W. Riding of Yorkshire No. II.	0·58	3·16	3·74	1·50
West Hallam No. II.	..	2·60	..	0·45
Clarence No. III.	0·65	2·16	2·81	0·66
Hematite No. III.	0·30	3·70	4·00	0·30
Coltness No. III.	0·28	2·54	2·82	0·67
Clarence No. III.	0·12	3·33	3·45	0·82
„ „	0·10	2·64	2·74	0·71
Phœnix No. III.	0·61	2·97	3·58	0·86
Gutehoffnungshütte No. III.	0·50	2·93	3·43	0·16
No. III.	1·52	1·95	3·47	0·95

IRONS AND STEELS.

Pig Irons.

Silicon.	Phosphorus.	Sulphur.	Copper.	Remarks.
3·50	0·98	0·02	..	Coke furnace.
0·97	0·50	0·05	..	Cold blast.
1·48	0·43	0·03	..	„ „
2·50	0·05	0·03	..	Coke furnace.
2·93	0·75	0·04	0·07	„ „
2·52	1·49	0·05	0·04	„ „
2·11	0·85	0·02	0·04	„ „
2·45	0·97	0·01	0·06	„ „
3·03	0·97	0·02	0·07	„ „
2·25	0·05	0·02	..	„ „
3·00	0·04	0·02	..	„ „
1·70	1·24	0·13	..	„ „
1·70	0·36	0·07	..	„ „ cold blast.
2·34	0·51	..	..	„ „
2·25	0·05	0·05	..	„ „
2·57	1·03	0·04	..	„ „
1·95	0·05	0·04	..	„ „
2·40	0·04	0·02	..	„ „
1·60	0·64	0·07	trace	„ „
1·26	0·72	0·05	..	„ „
1·79	1·80	0·10	..	„ „
2·00	0·05	0·07	..	„ „
2·16	0·51	..	0·08	„ „
3·08	1·80	0·02	0·04	„ „
4·37	..	..	trace	„ „
1·61	0·79	0·04	0 05	„ „
1·87	0·93	0·01	0·05	„ „
1·75	0·04	0·06	..	„ „

FOUNDRY

Name of Pig.	Combined Carbon, α C.	Graphitic Carbon, β C.	Total Carbon.	Manganese.
Viscaya No. III.	..	..	..	0·90
Cleveland No. III.	..	..	3·41	0·40
W. Riding of Yorkshire N. III.	0·39	3·36	3·75	1·50
Hematite No. IV.	0·70	3·00	3·70	0·25
Terre Noire No. IV.	2·08	1·15	3·23	0·65
Viscaya No. IV.	..	..	..	0·50
Cleveland No. IV.	..	..	2·66	0·90
W. Riding of Yorkshire No. IV.	0·32	3·31	3·63	1·20
Terre Noire No. V...	2·17	0·85	3·02	0·58
Viscaya No. V.	..	..	..	0·60
Viscaya No. VI.	..	..	..	0·50
„ No. VII.	..	..	..	0·40
Hematite mottled	1·70	1·50	3·20	0·10
Schwechat	..	..	3·39	4·43
Rokycan	..	..	2·79	trace
Eisenertz	..	..	2·82	3·79
Dernö	..	..	2·94	2·75
Welston } Ohio	..	2·57	..	..
Globe } Softeners!	0·30	2·85	3·10	1·00
Micheville	..	..	2·50	..
Marnaval St.-Dizier	..	..	4·25	..
Soc. Aciéries de France	..	..	4·00	1·85
Firminy	..	..	3·40	0·10
Weardale	..	2·20	..	0·13
Lays	..	3·20	..	1·14
Micheville	..	..	4–4·5	0·6–0·9
Poughkeepsie	..	..	4·24	1·46
Bushong	..	..	3·34	0·14
Bellefonte..	0·30	3·18	3·48	0·50
Lerbach	0·48	3·85	4·33	..

PIG IRONS—*continued.*

Silicon.	Phosphorus.	Sulphur.	Copper.	Remarks.
1·80	0·04	0·03	..	Coke furnace.
0·90	1·23	0·17	..	,, ,,
1·40	0·60	0·06	..	,, ,,
1·75	0·05	0·10	..	,, ,,
1·55	0·04	0·07	..	,, ,,
0·80	0·04	0·10	..	,, ,,
1·90	1·00	trace	..	,, ,,
1·40	0·60	0·08	..	,, ,,
1·45	0·05	0·09	0·26	,, ,,
1·00	0·04	0·06	..	,, ,,
0·80	0·04	0·10		
0·60	0·04	0·15		
1·00	0·05	0·25		
1·64	0·14	0·02	..	Doubtful suitability.
4·82	1·28	0·01	0·02	,, ,,
2·83	0·12	0·03	0·01	,, ,,
3·37	0·15	0·03	trace	,, ,,
6·67	0·50	trace		
5·89	1·10	0·02		
2·60	1·80	0·04		
2·25	0·75	0·03		
3·25	0·05	0·02		
3·20	0·07	0·02		
1·88	0·19	0·10		
1·05	0·29	0·05		
2·5–3·0	0·4–0·8	trace –0·05		
3·00	0·15	0·05	..	Anthracite furnace.
1·93	1·09	0·01		
2·60	0·35	0·03		
0·79	1·22	0·02	..	Charcoal furnace.

FOUNDRY

Name of Pig.	Combined Carbon, α C.	Graphitic Carbon, β C.	Total Carbon.	Manganese.
Finspong	1·75	2·17	3·92	0·19
Mariezell grey	0·71	3·07	3·78	2·52
„ mottled	0·75	2·26	3·01	2·33
Ilsenburg grey	0·41	2·78	3·19	0·41
„ mottled	0·40	2·53	2·93	0·35
„ „	0·79	2·40	3·19	0·28
„ white	1·58	1·63	3·21	0·14
Kallich grey	..	..	3·11	0·18
Plosko „	0·62	3·19	3·81	1·69
Sulz „	1·05	2·78	3·83	1·17
Szalocz „	0·36	3·31	3·67	2·13
Krompach „	1·15	2·35	3·50	2·44
Rhonitz „	0·50	2·34	2·73	1·42
Diosgyör mottled	0·74	1·78	2·52	2·08
Pion grey	0·80	2·88	3·68	0·17

BESSEMER

Workington	0·24	3·85	4·09	1·15
Hoerde	..	..	3·76	5·26
Georg Marienhütte	0·76	4·00	4·76	3·41
„ „	0·66	3·10	3·76	3·90
„ „	0·17	2·97	3·14	3·78
Schwechat	..	..	3·57	3·74
Hughes	0·62	3·11	3·73	0·22
Stenay	..	..	..	0·50
American	..	..	3·40	0·50
Nichnje Soldinsk	..	..	3·86	2·37
„ „	..	..	3·70	2·60

PIG IRONS—*continued.*

Silicon.	Phosphorus.	Sulphur.	Copper.	Remarks.
0·97	0·05	0·12	..	Charcoal furnace.
1·35	0·03	0·05	0·11	„ „
1·79	0·04	0·03	0·05	„ „
2·20	0·51	0·07	0·05	„ „
1·68	0·54	0·07	0·08	„ „
1·02	0·59	0·09	0·10	„ „
0·76	0·56	0·14	0·09	„ „
1·83	..	0·04	0·17	„ „
1·45	0·37	0·01	..	„ „
0·82	0·09	0·04	..	„ „
1·07	0·07	0·03	0·07	„ „
1·48	0·12	0·05	0·34	„ „
1·76	0·36	0·12	0·05	„ „
2·54	0·15	0·64	0·32	„ „
2·24	0·14	0·01	..	„ „

PIG IRONS.

2·20	0·10	0·05		
2·59	0·14	0·03		
3·31	0·07	0·05		
2·32	0·07	0·03		
1·73	0·08	0·04		
2·31	0·07	0·03		
1·81	0·07	0·03		
2·50	0·06	0·04		
0·70	0·08	0·07	..	Overheated into converter.
1·31	..	..	..	„ „ „
0·75	..	..	..	„ „ „

BASIC

Name of Pig.	Combined Carbon, α C.	Graphitic Carbon, β C.	Total Carbon.	Manganese.
Ilsede	..	..	2·68	3·84
Peine best	..	..	..	2·20
„ limits	..	..	..	2–2·50
Luxembourg average	..	..	..	1·5
„ limits	..	..	..	1–1·5
„	..	..	..	0·63
„	..	..	..	0·61
Hoerde	..	..	..	1·03
„	2·83	..	..	2·2–3·0
Ruhrort	..	..	..	0·41
Rothe Erde	..	..	..	1·50
Angleur	..	..	..	1·0–1·5
Ongrée	..	..	..	1·00
Le Creusot	3·00	..	..	1·5–2·0
Witkowitz	..	..	..	1·18
„	..	..	..	1·16
„	..	..	..	0·79
Kladno	3·50	..	..	0·40
Middlesborough	3·50	..	..	1·00
Longwy	..	..	3·00	1·50
„	..	..	3·20	2·00
Hollerich	..	..	..	trace
„	..	..	..	trace
Rheinische Stahlwerk	..	..	..	1·25
Eston	..	..	3·4	0·70

FORGE

Cleveland mottled	..	..	3·55	0·79
„ white	..	..	3·20	0·60
„	..	..	3·36	0·00

PIG IRONS.

Silicon.	Phosphorus.	Sulphur.	Copper.	Remarks.
0·11	3·29	0·04		
0·50	3·00	0·08		
0·5–0·7	1·5–3	0·08–0·05		
0·75	2	0·5		
0·1–0·8	1·2–2·5	0·13–0·6		
1·19	1·86	0·05		
1·32	1·75	0·08		
1·22	2·18	0·08		
0·40	1·5–2·5	0·01		
0·56	1·40	0·41		
0·80	2·00			
1·0–1·25	1·50–2·0	0·25		
1·25	1·39	0·10		
1·3	2·5–3·0	0·20		
0·42	2·47	0·13		
0·11	3·46	0·09		
0·75	0·90	0·20	0·07	
1·25	1·50	1·05		
1·00	2·75	0·12		
0·20	2·00	0·04		
0·35	2·20	0·02		
2·50	1·80	0·07		
0·90	1·99	0·10		
1·25	1·75			
1·70	1·50			

PIG IRONS.

0·66	1·05	0·35		
0·64	1·32	0·20		
1·60	1·55	0·14		

BASIC

Name of Pig.	Combined Carbon, α C.	Graphitic Carbon, β C.	Total Carbon.	Manganese.
Dowlais mottled	..	..	2·95	0·23
„ white	..	..	2·84	0·14
Hematite mottled	1·70	1·50	3·20	0·10
„ white	3·10	trace	..	0·10
Clarence white	..	..	3·50	0·30
„ „	..	..	3·20	0·60
Yorkshire „	..	..	3·69	0·00
Luxembourg white	1·10	0·47	1·57	0·44
Lorne „	..	..	3·69	0·06
Vordernberg	..	..	2·58	1·42
Schwechat	..	..	3·24	2·38
Betler	..	..	3·56	2·47
Eisenertz	..	..	3·19	2·47
„	..	..	3·98	2·18
Dobshau	..	..	..	2·19
Micheville grey	..	..	3·5–4·0	1·0–1·5
„ white	..	..	3·0–3·5	0·8–1·0
„ „	..	..	3·5–4·0	4·5–5·0
Marnaval St.-Dizier grey ..	..	..	3·75	1·25
„ „ white ..	..	..	3·25	0·90
Firminy white	..	..	3·20	1·02
Juniata	..	..	2·89	..
Nova Scotia	..	..	3·27	0·40
Swedish	..	..	4·0–4·5	trace–1·8
Osterby	4·62	..	..	0·89
Wattholm	4·25	0·43	4·68	0·28
Strömsberg	2·46	2·15	4·61	0·86
Söderfors	1·20	3·48	4·68	0·64
Vordernberg fined iron	..	..	0·16	0·06
Schwechat „ „	..	..	0·08	0·08

PIG IRONS—*continued.*

Silicon.	Phosphorus.	Sulphur.	Copper.	Remarks.
1·96	0·63	0·28		
1·21	0·64	0·46		
1·00	0·05	0·25		
0·80	0·05	0·30		
0·30	1·37	trace	..	Cold blast, Ca 0·3 per cent.
0·60	1·32	0·20	..	Hot blast, Ca 1·3 „ „
1·30	0·56	0·03		
0·40	1·62	0·30		
0·28	..	0·01	..	Charcoal.
0·11	0·07	0·04	trace	Cold blast.
0·15	0·14	0·04		
0·08	0·54	0·03	0·03	
0·57	0·10	0·06	trace	
0·17	0·07	0·02	trace	
0·39	0·13	0·05	0·08	
0·5–0·45	0·4–0·8	0·03–0·07		
0·2–0·6	0·4–0·8	0·04–0·08		
0·1–0·35	0·4–0·8	trace–0·03		
0·75	0·60	0·05		
0·40	0·60	0·06		
0·40	0·07	0·07		
0·80	..	0·01		
0·40	0·28	0·01		
0·2–0·5	0·01–0·15	0·01–0·03	..	For Lancashire hearth.
0·19	0·01	0·03		
0·25	0·01	0·03		
0·44	0·01	0·02		
0·80	0·02	0·02		
0·03	0·04	0·01	trace	
0·03	0·06	0·01	0·01	

SPIEGEL-

Name of Pig.	Combined Carbon, α C.	Graphitic Carbon, β C.	Total Carbon.	Manganese.
Hoerde	0·35	3·20	3·55	6·70
Wissen	4·10	..	..	11·10
Vulcan	..	..	4·77	18·70
Krupp	..	..	5·30	11·30
Rechitza	5·26	0·13	5·39	7·05
Georg Marienhütte	2·49	2·71	5·20	4·47
Gleiwitz	2·76	0·75	3·51	3·36
St. Louis	..	..	5·45	4·00
Müsen	..	..	4·25	12·07
„	..	..	4·41	10·93
Marnaval St.-Dizier	..	..	3·75	4·75
Firminy	..	..	4·00	15·00
St. Louis	..	..	5·75	18·50

FERRO-

Terre Noire	..	..	5·25	20·50
„ „	..	..	6·00	51·80
„ „	..	..	5·40	74·90
„ „	..	..	6·50	87·90
Rechitza	..	..	4·01	28·35
Oberhausen	..	..	5·53	35·43
Hoerde	..	..	5·31	55·06
Rechitza	..	..	6·21	69·64
Phœnix	..	..	6·94	76·95
Siegen	..	..	4·8–5·6	14–20
St. Louis	..	..	6·00	63·69
„ „	4·79	0·14	5·93	46·19
„ „	6·54	0·56	7·10	85·40
„ „	5·72	0·28	6·00	27·41
hes	..	..	4·00	45·50

IRONS.

Silicon.	Phosphorus.	Sulphur.	Copper.	Remarks.
2·20	0·30	0·08		
0·25	0·03	0·06		
0·09	0·28	0·01		
trace	0·01	trace		
0·52	0·21	trace		
0·80	0·07	0·04		
1·23	0·89	0·05		
0·19	0·02	0·01		
0·89	0·08	0·01		
0·69	..	0·01		
0·23	0·58	0·02		
4·50	0·07	0·01		
0·17	0·08	0·01		

MANGANESES.

0·46	0·08	..		
0·46	0·13	..		
1·73	0·24	..		
1·49	0·29	..		
0·90	0·24	..		
0·06	trace	..		
2·52	0·38	..		
0·28	0·06	..		
0·02	0·24	..		
0·32	0·08	..		
0·19	0·01	0·02		
0·14	0·10	0·01		
0·47	0·17	trace		
0·23	0·06	0·01		
..	0·25	..		

FERRO-

Name of Pig.	Combined Carbon, α C.	Graphitic Carbon, β C.	Total Carbon.	Manganese.
Clarence (glazy iron)	0·29	2·59	2·88	0·77
St. Louis	0·21	3·44	3·65	0·84
„ „	..	..	2·65	20·50
„ „	..	..	2·10	6·50
„ „	..	2·10	2·10	2·50
Terre Noire	..	..	2·65	20·50
Hematite (glazed)	..	3	..	0·50
Hollway	..	0	2·13	28·89
„	..	0	3·01	25·70
„	..	0	3·56	27·13
„	..	..	2·72	24·36
„	..	..	2·42	2·11
Mont Real	1·84	0·52	2·36	3·86
Soc. Aciéries de France	..	..	3·50	1·75
Firminy	..	..	1·42	18·09
Middlesborough	..	..	1·40	2·10
„	..	..	1·39	19·25
Clarence (glazed pig)	0·79	2·59	3·38	0·70
„ „	0·71	2·68	3·39	0·60

FERRO-

Keifenheim	..	..	4·85	1·10
„	..	..	4·70	13·20
Firminy	..	..	3·80	2·50
Adour 1	..	..	11·25	0·43
„ 2	..	..	12·00	0·43
„ 3	..	..	9·55	0·45
„ 4	..	..	8·50	0·80
5	..	..	9·38	0·50

SILICONS.

Silicon.	Phosphorus.	Sulphur.	Copper.	Remarks.
5·13	1·12	0·17		
4·89	0·06	..		
10·20	0·19	..		
5·55	0·14	..		
12·60	0·09	0·05		
10·20	0·18	..		
6·50	0·05	trace		
8·81				
6·72				
4·58				
9·19				
8·33				
10·55	0·04	0·03		
9·00	0·05	0·01		
17·00	0·09	trace		
12·05	0·04	0·01	0·01	
12·25	0·05	trace	0·01	
5·10	1·12	0·17	..	Ca 0·22, Mg 0·60, Ti 0·26
5·10	1·12	0·23	..	„ 0·20 „ 0·30 „ 0·18

CHROMES.

			Chromium.	
1·50	..	0·09	30·20	
..	..	..	25·30	
4·50	0·08	0·02	23·00	
..	..	..	62·70	
..	..	..	64·80	
..	..	..	60·35	
..	..	..	44·80	
..	..	..	57·96	

FERROCHROMES—

Name of Pig.	Combined Carbon, α C.	Graphitic Carbon, β C.	Total Carbon.	Manganese.
Adour 6	..	..	10·56	0·40
Tasmanian	..	..	4·20	..
„	..	..	..	trace
„	..	..	4·42	0·14
Unidex	..	..	0·44	..
„	..	..	2·52	0·51
„	..	..	5·40	..
Holtzer	..	..	11·00	..
„	..	..	7·50	..
„	..	..	8·10	..
„	..	..	7·50	..
„	..	..	1·20	..
„	..	..	5·00	0·40
„	..	..	3·40	..
„	..	..	7·30	0·40
„	..	..	4·70	..
„	..	..	2·70	..

FERRO-

Terre Noire	..	..	5·65	41·15
„	..	..	1·17	trace

FERRO-

Cowles	..	..	2·92	0·31
Berlin	..	..	0·55	trace
Champigneville	..	..	2·30	..

continued.

Silicon.	Phosphorus.	Sulphur.	Chromium.	Remarks.
..	0·08	0·02	64·50	
0·98	0·06	0·21	6·29	
1·44	0·09	0·21	6·55	
1·52	..	0·10	7·05	
..	..	..	54·53	
..	..	0·05	14·45	
..	..	..	67·20	
..	..	..	80·00	
2·00	..	..	50·00	
1·70	..	..	48·20	
8·20	..	..	82·00	
..	..	..	7·00	
0·40	..	..	7·00	
..	..	..	71·50	
2·10	..	..	43·00	
..	..	..	30·00	
0·40	..	..	16·00	

TUNGSTEN.

			Tungsten.	
..	0·14	..	24·25	
0·61	..	..	29·12	

ALUMINIUM.

			Aluminium.	
2·48	0·03	..	6·50	Cu 1·05
0·50	trace	trace	12·44	
2·60	..	..	0·50	

CAST

Name of Pig.	Combined Carbon, α C.	Graphic Carbon, β C.	Total Carbon.	Manganese.
Finspong gun iron	0·44	2·26	2·70	0·32
„ „	0·80–1·40	2·40–1·80	..	0·20–0·30
„ „	0·78	2·31	3·09	1·50
Mariazell „	0·71	2·87	3·58	0·83
Chilled iron	..	..	3·82	2·85
„ „	..	..	2·70–3·50	1·0–1·20
Hughes	0·50	3·60	4·10	1·69
American gun iron 1A	1·78	2·06	3·84	..
„ „ 2A	1·46	2·30	3·76	..
„ „ 3A	0·82	2·83	3·65	..
Swedish „	1·40	2·50	3·90	..
„ „	1·56	2·30	3·86	..
„ „	1·71	2·15	3·86	..
Åker „	1·20	2·90	4·10	..
„ „	1·15	..	..	..
Pressure cylinder	0·49	2·23	2·72	0·45
Pipes for hot-blast stoves ..	..	..	3·0–3·50	0·50–1·0
Woolwich	..	2·6	..	..
„	..	2·6	..	..
„	..	3·35	..	..
„	0·90	2·79	3·69	1·30
„	0·65	2·81	2·46	1·72
Chilled rolls	..	..	3·70–3·0	1·00
„ tyres	..	..	3·25	1·00
„ „ (American) ..	0·70–1·50	..	3·25–3·75	0·50
„ armour plate	..	..	3·0–3·30	1·00
„ „ „	0·95	2·32	3·27	0·35
„ „ „	1·07	2·25	3·32	0·22
Muirk (guaranteed)	..	..	2·90	0·60–1·50

IRONS.

Silicon.	Phosphorus.	Sulphur.	Copper.	Remarks.
0·63	trace	0·15	trace	R = resistance to tension in kg. per sq. mm.
0·90–0·60	0·07	1·11–0·15	..	„ 20 kg.
1·31	0·29	0·09	..	„ 34 „
0·70	0·07	..	0·09	
0·82	0·11	0·01	0·15	
0·50–1·0				
2·10	0·59	0·02		
..	..	..	..	„ 20 „
..	..	..	..	„ 17 „
..	..	..	..	„ 14 „
0·70	0·70	..	..	„ 18 „
0·60	0·70	..	..	„ 18 „
0·56	0·70	..	..	„ 16 „
0·83	0·70	..	..	„ 12 „
0·44	0·70	..	..	„ 8 „
2·22	0·93	0·13		
1·0–1·50	0·50			
1·26	0·72	0·05	..	„ 21 „
1·40	0·70	0·04	..	„ 18 „
1·75	1·38	0·04	..	„ 18 „
0·50	0·48	0·06	..	„ 20 „
0·48	0·56	0·06	..	„ 17 „
0·50				
1·00				
0·80	0·45	0·10		
0·48				
0·84	0·31	0·03	..	„ 27 „
1·15	0·72	0·06	..	„ 22 „
0·60–0·90	0·22–0·28	0·02–0·05	..	„ 28 „

WELD

Name of Pig.	Combined Carbon, α C.	Graphic Carbon, β C.	Total Carbon.	Manganese.
Danemora bar steel	..	..	0·84	0·05
Mägdesprung bar iron	..	..	0·40	0·30
South Wales „ „	..	..	0·41	0·04
Swedish iron	..	..	0·18	..
Pure Swedish iron	..	..	0·27	trace
Swedish Lancashire iron ..	..	.	0·06	..
„ „ „ ..	..	..	0·05	..
„ puddle iron	..	..	0·07	..
Yorkshire puddle iron, best ..	..	..	0·07	..
„ „ „ „ ..	..	..	0·15	..
Staffordshire puddle iron, best	..	..	0·06	..
North-Eastern R. C. rails ..	..	..	0·08	0·16
„ „ „ „ ..	..	..	..	..
West Yorkshire tyre	..	..	0·10	0·08
„ „ angle iron ..	..	..	0·11	0·06
„ „ railway axle	..	..	0·12	..
„ „ „ „	..	..	0·14	0·01
„ „ boiler plate ..	..	..	0·08	0·03
„ „ crank axle ..	..	..	0·05	0·06
„ „ bar iron ..	..	..	0·02	..
Motala (Lancashire)	..	..	0·06	..
Degerfors „	..	..	0·05	..
Avesta „	..	..	0·07	..
Surahamman puddled	..	..	0·05	..
Motala „	..	..	0·04	..
Unieux	..	..	0·14	..
Rechitza	..	..	0·21	0·01
Armour plate, Kolpino	..	..	0·09	0·09
„ „ „	..	..	0·06	0·17
„ „ „	..	..	0·08	0·03

IRONS.

Silicon.	Phosphorus.	Sulphur.	Copper.	Remarks.
0·12	0·07	..	0·07	*e* = elongation in p.c. in 200 mm.
0·01	..	..	0·23	E = elastic limit in kg. per sq. mm.
0·08	0·04	..		
0·08	..	0·03		
0·07	0·02	0·04		
0·04	0·02	0·02	..	R 34 kg.; E 13 kg.; *e* 21 p.c.
0·02	0·03	0·01	..	„ 31 „ „ 16 „ „ 26 „
0·10	0·02	..	..	„ 33 „ „ 16 „ „ 22 „
0·06	0·09	..	..	„ 36 „ „ 19 „ „ 10 „
0·21	0·12	..	..	„ 39 „ „ 18 „ „ 10 „
0·20	0·25	0·02	..	„ 34 „ „ 15 „ „ 9 „
0·16	0·32	0·04	..	} Dank's furnace.
0·11	0·17	0·03	..	
0·17	0·09	0·01		
0·14	0·09	0·02		
0·15	0·09	0·01		
0·25	0·09	0·02		
0·12	0·08	0·02		
0·10	0·03	0·01		
0·16	0·22	0·01		
0·05	0·02	0·02		
0·02	0·03	0·01		
0·10	0·02	0·02		
0·08	0·02	..		
0·11	0·02	trace		
0·10	..	0·03		
0·03	0·01	..	..	R 34 kg.; *e* 27 p.c.
0·12	0·12			
0·20	0·36			
0·15	0·40			

WELD IRONS—

Name of Pig.	Combined Carbon, α C.	Graphic Carbon, β D.	Total Carbon.	Manganese.
Armour plate, Kolpino	..	..	0·09	0·10
„ „ Cammell	..	..	0·06	0·15
„ „ Dillingen ..	..	..	0·07	0·09
„ „ „ ..	..	..	0·07	0·19

STEEL.

Name of Object.	Carbon.	Manganese.	Silicon.	Phosphorus.
1. RAILWAY MATERIAL.				
Ideal rails, Dudley	0·3	0·35	0·04	0·10
„ „ Snelus	0·35	0·75	0·10	0·07
„ „ Pourcel	0·45	1·00	0·02	0·09
Edgar Thomson rails	0·42	0·98	..	0·10
„ „ „ . ..	0·30	0·77	..	0·10
„ „ „	0·32	0·85	..	0·10
„ „ „	0·34	0·93	..	0·10
„ „ „	0·36	0·96	..	0·10
North-Eastern rails	0·45	0·18	0·11	0·05
„ „ „	0·45	1·20	0·07	0·05
Rails	0·46	0·45	0·10	0·08
„	0·21	0·37	0·03	0·04
„	0·34	0·62	0·08	0·06
„	0·24	1·55	0·27	0·09
„	0·40	0·75	0·04	0·09
„	0·24	0·73	0·06	0·04
„	0 33	0·80	0·02	0·06
„	0·41	1·40	0·05	0·04

continued.

Silicon.	Phosphorus.	Sulphur.	Copper.	Remarks.
0·16	0·17	0·03	0·07	As 0·01
0·02	0·20			
0·12	0·17			
0·20	0·70	0·01	0·02	

STEEL.

Sulphur.	R, kg.	E, kg.	*e* per cent.	*c* per cent.	Remarks.
..	..	..	..	..	R = ultimate strength in kg. per sq. mm.
..	..	..	..	..	
0·05	..	..	..	..	E = elastic limit in kg. per sq. mm.
..	71	45	15*	23	
..	57	36	19*	33	*e* = elongation in per cent. in 200 mm.
..	60	38	20*	34	*c* = contraction in per cent.
..	62	40	21*	34	
..	65	40	22*	44	* on 100 mm.
0.12	..	..	..	..	Haematite.
0·10	..	..	..	..	Cleveland basic.
0·06	66	..	9	8	Good.
0·07	45	..	25	51	
0·05	55	..	21	43	
0·05	61	..	6	8	
0·22	60	..	20	32	Excellent.
0·11	53	..	26	45	
0·13	65	..	20	43	
0·10	62	..	21	35	

STEEL—

Name of Object.	Carbon.	Manganese.	Silicon.	Phosphorus.
Rails	0·40	1·01	0·05	0·04
„	0·39	0·80	0·03	0·04
„	0·30	0·91	0·04	0·06
„	0·32	0·85	0·05	0·05
„	0·34	0·89	0·06	0·05
„	0·30	0·76	0·03	0·05
„	0·38	0·10	0·39	0·10
„	0·34	0·15	0·48	0·14
„	0·30	0·20	0·37	0·14
Hughes rails	0·40	0·70	0·03	0·07
Terre Noire rails	0·71	0·80	0·05	0·10
„ „ „	0·24	0·67	..	0·34
„ „ „	0·83	0·51	..	0·46
„ „ „	0·27	1·51	..	0·41
Gras rails	1·03	0·07	0·05	trace
Swiss rails	0·44	0·85	0·17	0·11
„ „	0·29	0·52	0·10	0·13
Arnold normal tyre	0·28	1·25	0·07	0·08
Pourcel tyre	0·30	0·45	0·18	0·10
Arnold „	0·25	1·75	0·03	0·11
Krupp „	1·09	0·52	0·26	0·11
Russian forged tyre .. .	0·59	0·41	0·11	0·08
„ „ „	0·69	0·60	0·10	0·06
„ „ „	0·78	0·39	0·07	0·08
„ „ „	0·60	0·40	0·12	0·08
„ „ „	0·87	0·39	0·11	0·08
Bochum tyre	0·93	0·56	0·04	..
Bochum crossing	1·31	0·98	0·09	0·13
Terre Noire carriage springs ..	0·87	0·27	trace	0·06

continued.

Sulphur.	R, kg.	E, kg.	*e* per cent.	*c* per cent.	Remarks.
0·11	65	..	20	43	
0·06	73	..	20	42	
0·08	61	..	23	40	Excellent.
0·06	58	..	23	44	
0·07	55	..	23	44	
0·07	67	..	25	50	
..	65	..	21	44	
..	71	..	18	28	Very bad.
0·20	75	..	20	40	
0·03	..	..	..	..	Open hearth.
trace	75	46	9	32	
..	59	43	7	7	Bessemer steel.
..	52	31	6	4	Open hearth steel.
..	54	41	7	13	„ „ „
0·05	74	..	3	..	Cu 0·08.
0.09	59	32	20	32	
0·07	59	39	20	40	
0·08	37	..	26	47	
0·05					
0·12	42	..	18	26	
0·05	..	..	..	..	Cu 0·2
..	90	..	10	11	
..	70	..	8	26	
..	70	..	7	30	
..	60	..	12	40	
..	77	..	6	26	
..	70				
0·05	..	..	..	..	Cu 0·26
trace					

STEEL—

Name of Object.	Carbon.	Manganese.	Silicon.	Phosphorus.
2. BRIDGE, BOILER, SHIP-PLATE.				
Forth Bridge	0·19–0·23	0·69	0·02–0·03	0·05
Motala	0·23	0·20	0·02	0·03
Terre Noire	0·71	0·80	0·05	0·10
Kladno	0·08	0·18	..	0·03
Phœnixville	0·15	0·50	0·01	0·04
Peine	0·08	0·45	trace	0·05
Angle steel	0·11	0·06	0·14	0·09
Terre Noire	0·28	0·69	0·23	0·07
„ „	0·46	0·67	0·22	0·07
„	0·87	0·77	0·32	0·08
Rechitza	0·22	0·35	0·03	0·01
„	0·18	0·12	0·01	0·01
Motala	0·10	0·15	0·03	0·03
„	0·17	0·27	0·03	0·03
Iggesund	0·10	0·09	0·02	0·02
Huddeholm	0·05	0·05	0·01	0·03
„	0·14	0·09	0·02	0·02
Seraing ship-plates 1	0·04	0·29	..	0·01
„ „ 2	0 09	0·29	..	0·01
„ „ 3	0·07	0·36	..	..
Obouchoff „	0·21	0·23	0·01	0·01
Boiler plate	0·23	0·61	0·02	0·04
„ „	0·17	0·24	0·03	0·05
„ „	0·08	0·13	0·12	0·08
„ „	0·16	0·38	0·01	0·03
3. ORDNANCE MATERIAL.				
Gun steel, from Krupp	0·45	..	0·16	0·04
„ „ „ „	0·60	0·18	0·19	trace
„ „ „ „	0·68	0·16	0·10	trace

continued.

Sulphur.	R, kg.	E, kg.	*e* per cent.	*c* per cent.	Remarks.
0·02					
0·01	40				
trace	71	36	14	25	
0·03					
0·11	40	..	30	55	
0·04	..	..	..	..	Basic steel.
0·02					
..	49	28	21	36	
..	56	30	17	23	
..	82	48	3	3	
..	35	..	32	72	
..	35	..	29	68	
0·01	..	..	..	..	Bessemer steel.
trace	..	..	..	..	Open hearth steel.
0·03	..	..	..	..	Bessemer „
..	..	..	..	..	„ „
trace	..	..	..	..	Open hearth „
0·01	..	..	..	..	„ „ „
0·01	..	..	..	..	„ „ „
0·01	..	..	..	..	„ „ „
trace					
0·08	..	..	..	..	„ „ „
0·07	..	..	..	..	„ „ „
0·02					
0·02					
0·02	50	18	19		
trace	..	..	..	..	Cu 0·27
trace	..	..	..	..	„ 0·35

STEEL—

Name of Object.	Carbon.	Manganese.	Silicon.	Phosphorus.
Gun steel, from Krupp	0·46	0·13	0·11	..
,, ,, ,, ,, ...	0·52	0·07	0·09	..
,, ,, ,, ,, ...	0·71	0·16	0·07	trace
,, ,, ,, ,, ...	0·40	0·18	0·20	0·03
,, ,, ,, Terre Noire ..	0·49	0·20	..	0·07
,, ,, ,, ,, ,, ..	0·46	0·67	0·22	0·08
,, ,, ,, ,, ,, ..	0·12	0·53	0·23	0·01
,, ,, ,, Woolwich ..	0·25–0·50	0·80–0·05	..	..
,, ,, ,, Trubia	0·23–0·33	0·32–0·38	0·05–0·06	0·01
,, ,, ,, Firth	0·34–0·40	0·08–0·13		
,, ,, ,, Vickers	0·24–0·27	0·22–0·23		
,, ,, ,, Cammell ..	0·14–0·19	0·34–0·25		
,, ,, ,, Whitworth ..	0·30–0·42	0·31–0·24		
,, ,, ,, Witten	0·47	0·41	0·44	0·08
,, ,, ,, Bofors	0·40	0·61	0·32	0·05
,, ,, ,, ,, ...	0 45	0·54	0·35	0·02
,, ,, ,, ,, ...	0·50	0·36	0·18	0·04
Fermeture piece, Krupp	0·21	..	0·17	0·09
,, ,, ,, ...	0·48	..	0·20	0·05
Shot (point) ,, ...	0·89			
,, (base) ,, ...	0·86			
,, Bofors	0·77	0·27	0·45	..
,, Algerian (ancient)	..	..	..	..
,, Sinopé ,, ...	..	..	..	..
,, steel, from Krupp	0·45	0·20	0·21	
,, ,, ,, Le Creusot ..	0·38	0·45	0·09	
,, ,, ,, Firth	0·46	0·13	0·12	
,, ,, ,, Whitworth ..	0·29	0·40	0·01	
,, ,, ,, Cammell	0·37	0·51	0·07	
,, ,, ,, R. G. F.	0·29	0·89	0·02	

continued.

Sulphur.	R, kg.	E, kg.	*e* per cent.	*c* per cent.	Remarks.
..	..	..	..	..	Cu 0·30
..	..	..	..	..	„ 0·35
..	..	..	..	..	„ 0·26
0·02	..	..	..	..	„ 0·13
..	48	26	24	..	Forged.
..	59	34	19	..	Cast.
0·02	66	30	19	48	
..	47–70				
trace					
0·04	62	26	14	45	
0·02					Open hearth.
..	60*	25*	20*	50*	* About.
0·02					
0·04	59	22	19		
0·02	58	22	19		
..	..	..	..	..	Cr 1·89.
..	..	..	..	..	As 10–27.
..	..	..	..	..	As 16.

STEEL—

Name of Object.	Carbon.	Manganese.	Silicon.	Phosphorus.
Armour plate, Cammell	0·57	0·62	0·17	0·05
,, ,, ,, ...	0·84	2·06	0·38	0·09
,, ,, ,, ...	0·75	1·45	0·18	0·06
,, ,, ,, ...	0·66	0·93	0·10	0·03
,, ,, Dillingen ..	0·55	..	0·40	0·25
,, ,, Cammell ..	0·90	1·80	0·28	0·07
,, ,, Brown	0·78	0·98	0·17	0·07
,, ,, Le Creusot ..	0·41	0·29	0·07	0·04
,, ,, Brown	0·62	0·90	0·12	..
Hoops, Terre Noire	0·30	0·53	0·18	..
Rifle steel, Solingen .. .	0·13	0·14	0·11	0·08
,, ,, Spain	0·43	0·40	0·20	0·05
,, ,, Prussia	0·46	0·40	0·10	0·06
,, ,, Witten	0·47	0·41	0·44	0·08
,, ,, Unieux	0·60	0·10	..	..
,, ,, Firminy	0·57	0·11	0·09	0·07
,, ,, ,, ...	0·40	0·27	..	..
,, ,, St. Chamond ..	0·49	0·13	..	..
,, ,, Terre Noire	0·30	0·29	..	..
,, ,, ,, ,, ...	0·32	0·72	..	..
,, ,, Fagersta	0·15	0·17	0·02	0·03
4. MISCELLANEOUS.				
Die steel, Royal Mint I. ..	0·82	0·10	0·05	..
,, ,, ,, ,, II.	1·07	0·12	0·06	trace
,, ,, ,, ,, III. ..	0·79	0·24	0·18	0·01
,, ,, ,, ,, IV. ..	1·19	0·45	0·29	trace
,, ,, ...	0·82	0·08	0·06	0·03
,, ,, Brussels	0·79	0·32	0·14	0·03
,, ,, ,, ...	0·94	0·30	0·15	0·03

continued.

Sulphur.	R, kg.	E, kg.	*e* per cent.	*c* per cent.	Remarks.
0·05	..	..	..	..	Steel face; Cu 0·03.
0·06	..	..	..	..	„
0·05	..	..	..	..	„
0·05	66	..	1	..	„ Cu 0·02.
..	..	..	..	..	„
..	68	..	2	..	Cu 0·02
..	56	30	16	72	
0·02					
0·05					
0·04					
0·04					
..	54	26	21*		* on 100 mm.
..	56	37	26*		
..	53	38	27*		
..	63	38	21*		
trace					
trace					
trace					
0·01	..	..	..	..	Cu 0·02.
trace					
trace					
trace					
trace					

STEEL—

Name of Object.	Carbon.	Manganese.	Silicon.	Phosphorus.
Die steel, Dutch Mint	0·79	0·25	0·19	0·01
„ „ Paris	0·86	0·10	0·06	0·01
„ „ „	0·79	0·10	0·06	0·01
Spring steel	0·52	0·03	0·15	0·06
„ „	0·76	0·09	0·84	0·02
Swords	0·64	0·45	0·26	0·02
Scythes	0·63	0·21	0·13	0·06
Axes	0·70	0·20	0·27	0·04
Agricultural steels	0·52	0·38	0·15	0·04
„ „	0·63	0·61	0·24	0·07
„ „	0·76	0·44	0·19	0·06
Cutlery steels	0·51	0·27	0·18	0·03
„ „	0·61	0·40	0·20	0·05
Steel pivot	0·81	0·12	0·12	trace
„ „	1·01	0·09	0·12	trace
„ axle	0·25	0·23	0·24	0·02
„ journal	0·56	2·00	0·09	0·06
„ shaft, Krupp...	0·30	0·57	0·18	0·09
„ stern-frame	0·23	0·80	0·25	0·04
„ wire..	0·16	0·16	0·20	0·08
„ „	0·21	0·32	0·07	..
„ „	0·18	0·28	0·05	..
„ „ Hoerde..	0·10	0·30	trace	0·03
„ machinery parts	0·25	0·23	0·24	0·02
„ screws	0·46	0·32	0·22	..
Retort manganese steel	0·47	0·54	0·05	0·05
Tool steels	0·88	0·14	0·22	0·02
„ „ Holtzer	1·13	0·05	0·05	0·03
„ „ „	0·73	0·05	0·05	0·03
„ „ „	1·08	0·04	0·05	0·03

continued.

Sulphur.	R, kg.	E, kg.	*e* per cent.	*c* per cent.	Remarks.
trace					
trace					
trace					
..	..	..	..	..	Figure for Mn. doubtful.
trace	84	45	11	25	
0·04	42	22	25		
0·03	47	..	23*	..	* on 100 mm.
..	39	24	32		
..	39	24	27		
trace	37				
..	40				
0·05					
..	75	56	8*		
..	72	48	6*		
..	72	54	4*		

STEEL—

Name of Object.	Carbon.	Manganese.	Silicon.	Phosphorus.
Musket special steel	2·00	0·20	0·10	..
Crescent Wo „	2·10	2·70	0·10	..
Imperial „ „	1·60	2·10	0 20	..
Böhler „ „	1·00	..	..	..
Sheffield special „	0·60	..	0·70	..
Howel Wo „	1·65	0·40	0·20	..
Bochum Wo „	1·40	1·73	..	..
Special Mn „	0·50	5·50	0·50	..
„ Si „	0·83	0·43	0·84	..
„ „ „	0·57	0·20	0·48	..
„ „ „	1·05	0·41	0·23	..
„ „ „	1·19	0·40	0·58	..
„ „ „	1·09	0·37	0·69	..
„ Cr „	0·45	0·75	0·28	..
„ Ni „	1·0–0·5	0·50	..	..
„ Al „	0·28	..	0·22	0·06

continued.

Sulphur.	R. kg.	E. kg.	e per cent.	c per cent.	Remarks.
..	..	..	..	..	Wo 7·8.
..	..	..	..	..	„ 6·7.
..	..	..	..	..	„ 6·4.
..	..	..	..	..	„ 2·5.
..	..	..	..	..	„ 9·3.
..	..	..	..	..	„ 2·9.
..	..	..	..	..	„ 1·9.
..	..	..	..	..	Cutting tool.
..	..	..	..	..	Wood working.
..	..	..	..	..	„ „
..	..	..	..	..	Turning tool.
..	..	..	..	..	„ „
..	..	..	..	..	„ „
..	..	..	..	..	Cr 0·75.
..	..	..	..	..	Ni 2·0–10·0.
0·01	40	19	19	20	Al 0·33.

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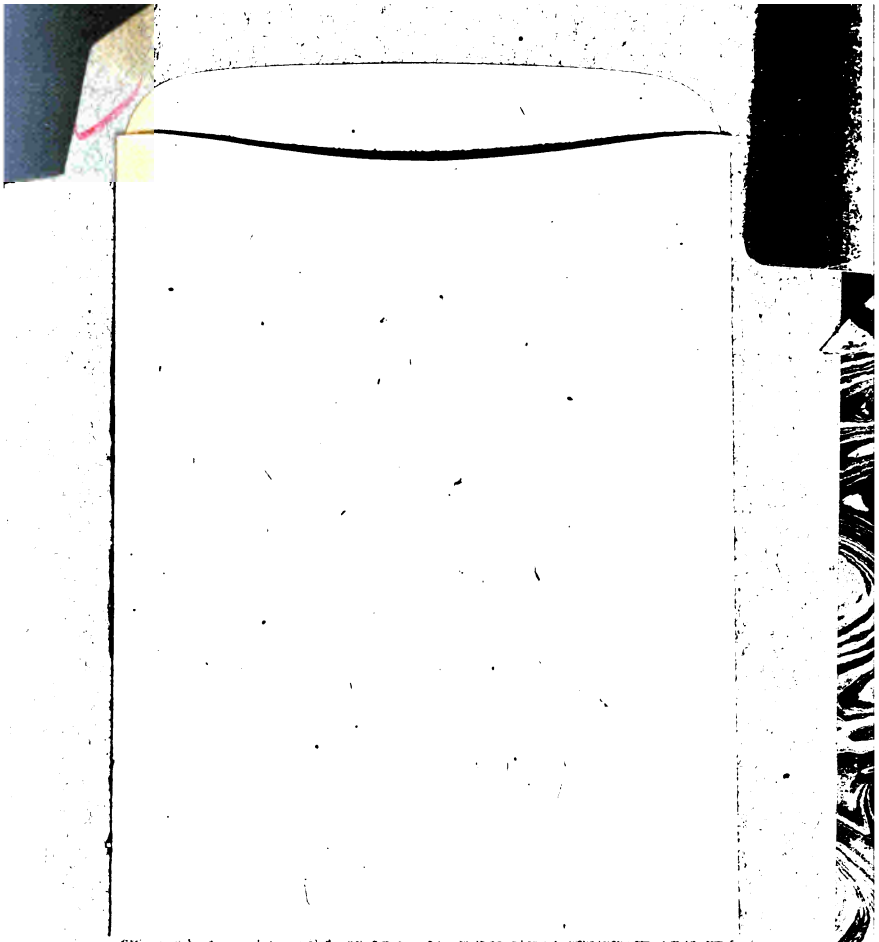

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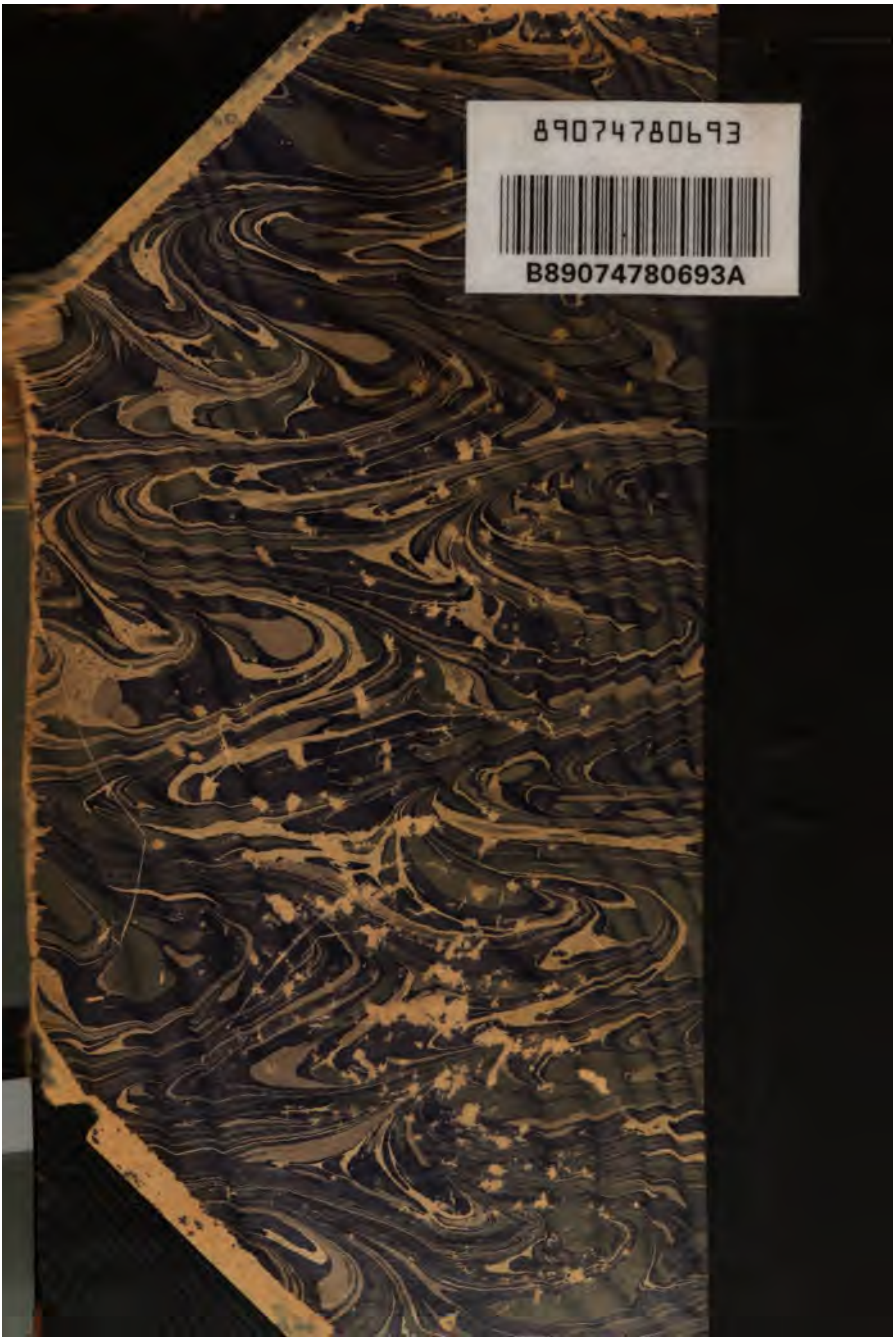
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